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REPAIR CYCLE BASE

SELF-SUFFICIENCY MODEL

THESIS

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Russell E. Ewan

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Abstract

The primary emphasis in this study is to develop a tool for use by base level managers in evaluating base self-sufficiency. Base self-sufficiency is gauged by the percent base repair (PBR) and repair cycle time (RCT) for those assets coded as reparable. This study focuses on incrementally increasing PBR and decreasing RCT to determine their effects on expected backorders, the fill rate and stockage cost.

The tool or model developed in this effort is a Fortran 77 program replicating existing Repair Cycle Demand Level (RCDL) conventions employed in the Air Force's Standard Base Supply System (SBSS). The Fortran 77 mode is used primarily because of its analytical capability and adaptability for microcomputer use at the base level. The data processed through the model is from RAF Upper Heyford, England collected by the Air Force Logistics Management Center.

In evaluating the sensitivity of PBR and RCT, the simple poisson distribution is used to describe demand and resupply probabilities. This particular distribution is widely used for solving inventory problems, it accurately describes reparable item demand, and is not computationally burdensome.

The results generally show RCT, for repaired items only (RCT1), and PBR are sensitive to the performance measures. RCT1 is sensitive to the expected backorder and fill rate performance measures and insensitive to the stockage measure because of an existing four day floor used in the RCDL model. RCT for unserviceable items sent to depot (NCT) is

insensitive to all three performance measures. Of particular significance is the sensitivity of PBR in reference to the stockage cost measure; raising PBR decreases stockage cost dramatically.

This study recommends the developed model be replicated and sent out to the field for base level use. In addition, a recommendation is made for Air Force managers to emphasize and push for increasing base repair capabilities to reap the benefits of the savings derived and improve operational stockage performance.

REPAIR CYCLE BASE SELF-SUFFICIENCY MODEL

I. Introduction

Background

The primary mission of the Air Force is to execute the defense policy of the United States with the principal aim of deterring enemy aggression. To do this, the Air Force must maintain a state of readiness able to meet any contingency and react effectively when called upon. This state of readiness is dependent upon many factors, one of which is the stockage, maintenance and management of spares, commonly referred to as stockage policy. With the increasing technological complexity of current weapon systems and equipment, spares support has taken on further importance in achieving national defense objectives.

The Logistics Long-Range Planning Guide (LLPG) completed in 1981 expresses four main logistics objectives, two of which directly apply to this research effort:

> (1) develop a means to better identify and assess logistics requirements and capability, especially as these relate to execution of U.S. contingency plans,

and

> (2) effectively manage or influence the management of scarce logistics resources to maintain Air Force combat capability (31:1).

The LLPG specifically addresses the intent of this research effort by stating, "greater emphasis must be placed on assessing and identifying logistics support capability in order to appraise realistically what can or can not be accomplished with available assets" (31:2). In essence, the Air Force is concerned with taking existing resources and using these to the best possible extent to meet any combat

contingency.

Recently, the Air Force supply community (headed by HQ USAF/LEY) initiated a program, Project Harvest Resource, to improve Air Force materiel management (2:1). This project includes 43 initiatives, one of which focuses on the requirement for analytical tools that will predict, not just react, in assessing Air Force stockage policies. This initiative primarily keys on those techniques pertaining to reparable spares and supply system performance (2:57). The agency given office of primary responsibility for this initiative is the Air Force Logistics Management Center (AFLMC) at Gunter AFS, AL.

AFLMC's role is "to conduct research necessary to examine and recommend improvements to base level stockage policy" (4:1). In the AFLMC Master Plan, one of the four main project areas is Retail Level Aggregate Management, where the intent is to provide base level users the tools necessary to manage supplies by taking full advantage of microcomputer technology (4:3-4). The ultimate objective of this research effort is to develop one of these "tools" for base level users in accordance with Project III. C. 2. titled Base Level Aggregate Inventory Management (4:16).

Base level stockage policy is divided into two categories of supply: consumable and reparable items. Consumables are those items "consumed" or used up in the process of their use. When a consumable item fails, it is disposed of. Consumable items are managed under the Economic Order Quantity (EOQ) inventory model (32:3). Reparables are those items that may be repaired and returned to a serviceable condition for reuse. These items are managed by the Repair Cycle Demand Level (RCDL) inventory model with selected items having an additional EOQ

component in the model (32:11-13).

Reparable items may be repaired at the field (on base) or depot level. The level of repair is dependent upon an item's Expendability Recoverability Reparability Cost (ERRC) code and Technical Order (T.O.) specifications (29:II-3-16). An item assigned an ERRC "XF" is authorized field level repair and an item with ERRC "XD" can be sent to depot for repair if field level repair is not authorized (per T.O. instructions) or resources are not available on base to do the repair.

Reparable items (or repair cycle items) are controlled on base via the repair cycle system which tracks the location and status of each item while in maintenance until it is turned-in to the base supply organization (29:III-3-5). Two measures of the repair cycle system which directly impact the base's stockage position are average Repair Cycle Time (RCT) and Percent Base Repair (PBR). Average RCT is the average time it takes to remove an item from a weapon system, repair or determine the disposition of the item, and turn it in to supply. RCT consists of two different types of times: average time to repair (labeled RCT1) and average time when an item is not repaired (labeled NCT, Not Reparable This Station/Condemned Time). PBR is a percentage taken from those items actually repaired on base divided by the total number of assets turned-in whether they were repaired, evacuated to depot or sent to disposal.

RCT and PBR are two ways to measure base self-sufficiency. Base self-sufficiency is defined as "full utilization of current base skills, tools, facilities and parts to accomplish presently authorized work" (10:5). In effect, the primary objective of base self-sufficiency is to achieve maximum maintenance at the field level and to reduce the

evacuation of spares to depot and disposal facilities, within the confines of base resources. Base self-sufficiency is dependent upon a maintenance organization's effectiveness to screen reparable property and use in-place assets to insure all property forwarded to depots for repair is unserviceable and actually beyond the base's repair capability (10:4). This is measured by PBR, previously defined as the percent of those items repaired on base versus the total number of assets turned-in. The better the percentage, given the same number of assets turned-in, the lower number of evacuations to depot. In addition, base self-sufficiency is also concerned with the efficiency of its maintenance capability or the time it takes to regenerate reparable spares or get an asset through the repair cycle. This efficiency factor is measured by RCT. RCT is the amount of lost utility an asset has by being "available" (in the repair cycle system), but not in a serviceable condition (30:19-20). Both the PBR and RCT are used in calculating an item's demand level, the quantity authorized for stock in base supply. This demand level is also an important parameter in calculating many performance measures. So by varying base self-sufficiency, as measured by PBR and RCT, the effects on performance indicators can be examined.

A base stockage policy is the aggregate effect of all those managing and maintaining the spares on a base. Some of the methods used by managers in managing and maintaining spares are provided below:

(1) Management emphasis on repair cycle delinquencies, repair cycle times, unserviceable assets being retained on systems, awaiting parts (AWP) retention policy, and degree to which AWP assets are cross-cannibalized (6:5-6).

(2) Effectiveness of Reparable Review Boards in identifying

improper evacuations to depot, lack of resources, shop backlogs, and items with excessive repair days (5:7-8).

(3) Evaluation inspections to determine availability of skills, correct tools, equipment, facilities, T.O. data, and bit and piece supply support to see whether base capabilities are being fully used and/or can be increased (29:III-3-16).

(4) Quality assurance inspections to insure Source, Maintenance and Recoverability (SMR) codes in T.O.'s are followed. The Functional Management Inspection of Supply Retention and Excess Policy (1 Dec 83-14 Jun 84) found 44% of those "XF" assets sent to disposal could have been repaired (3:25).

(5) Evaluation inspections of personnel distribution and scheduling, location of equipment and supplies, atmosphere of work areas, and use of facilities to determine optimal use of such resources (10:5).

(6) Review of manual receipt and organizational turn-in processing to detect errors which cause serviceable assets to be sent to disposal versus Air Force stock (3:52).

The results of these methods for managing base stockage determine, to a degree, the RCT and PBR levels achieved affecting the amount of money required for spares support.

Ninety-five percent of all the money spent on supplies stocked in a typical base supply organization is spent on repair cycle assets (6:5). This equates to an eight billion dollar investment. Repair cycle assets consist of only five percent of the total line items in the Air Force inventory because of their high cost and reparability. With a constrained budget and the increasing cost of more sophisicated spares,

the key to an effective stockage policy is using base resources to the fullest extent possible in repairing these assets. Given this, and the critical nature of these spares toward achieving the Air Force mission, stockage policy becomes an important factor in maintaining a credible defense posture.

General Issue

Air Force logisticians are concerned with providing predictive techniques versus reactive techniques, which are now widely used to give past performance status, to increase future mission capability. These predictive techniques are particularly necessary for inventory managers who manage reparable aircraft supplies at the Chief of Supply (base) level. Currently, a technique is required to assist managers in evaluating base self-sufficiency, or the degree to which a base uses its existing maintenance resources to regenerate repair cycle assets, to increase base capability.

Specific Problem

The objective of this research is to develop a model portraying the operational stockage effects of improving base self-sufficiency, as developed by those stockage policies and methods used, to base level managers. Once the model is developed, the base self-sufficiency parameters of average repair cycle time and percent base repair are varied to determine their effect on selected performance indicators.

Investigative Questions

(1) By using base maintenance resources for an expanded number of repairs, how much does an increase in the percent base repair rate improve base performance indicators?

(2) By using base maintenance resources more efficiently, how much does a decrease in average repair cycle time improve base performance indicators?

Summary

The two investigative questions coincide with the two parameters of base self-sufficiency, PBR and RCT, and ask how much does the improvement in these parameters effect the selected performance indicators. With these questions in mind and the objective of developing a tool for evaluating base self-sufficiency for field use, this report first outlines the applicable literature affecting this study. Of primary interest is the RCDL model and the various performance indicators. Next, the methodology is presented explaining the assumptions made, experimental design, data base and model development. The final two chapters analyze the results of processing the data through the model extrapolating some conclusions and recommendations from those results.

II. Literature Review

Introduction

This chapter reviews related works on inventory control theory providing relevant information to this research project and the necessary tools and concepts to build a model. A basic understanding of the Standard Base Supply System (SBSS) and the repair cycle concept is essential since this is the system of central issue. At the heart of this system is the Repair Cycle Demand Level (RCDL) inventory model. This model determines the actual stockage position of a base contingent upon the stockage policies used by its managers. The RCDL model is reviewed element by element to determine the internal workings for computing item requirements.

Once item requirements are determined, there must be a means for evaluating the effectiveness of these requirements. Here, Palm's theorem and the poisson distribution are discussed providing the background on performance measures used in evaluating reparable item inventory systems. Performance measures fall into two categories. The measures in each category have advantages and disadvantages according to their underlying assumptions and uses. These advantages and disadvantages are then reviewed.

Finally, an outline is provided on the history of reparable item models and prior sensitivity studies. The intent is twofold. The first is to examine the extent and direction of the evolution in reparable item modeling. Second is to determine whether there are any associated studies which contribute directly toward this effort.

Standard Base Supply System (SBSS)

The SBSS is the retail organization of the Air Force which deals with base users of supplies and equipment. It operates much the same as a private merchant in a local community (25:1). The SBSS receives its stocks from a variety of wholesalers, the primary being the Air Force's five Air Logistics Centers supplying Air Force peculiar items. Other wholesalers include General Services Administration (common, civilian type supplies and equipment), Defense Supply Agency (common items used in the Department of Defense), and local purchase sources.

Like any other retail outlet, the driving force in the SBSS is demand or requests for needed supplies (25:1). Most of the time, a request is filled from base stocks. But if an item is not available, a backorder is created, a due-out to the customer. This backorder is either satisfied through normal replenishment stocks due-in or a special order (requisition) to the appropriate depot. Once the item is sent by the source of supply and received by the SBSS, it is then released to the customer satisfying the initial request. Not all stocks in the SBSS are replenished strictly from wholesale sources. One other important source of supply, and the one of prime interest in this study, is the repair cycle system.

Repair Cycle System. The repair cycle system operates in the first echelon of a two echelon system (16:2) (see Figure 1). When an item fails in the course of operations, a maintenance technician pinpoints the failed item and orders a replacement item from supply. When the issue is made, the repair cycle time begins. The failed part is sent to a maintenance shop for base repair determination and repair if possible.

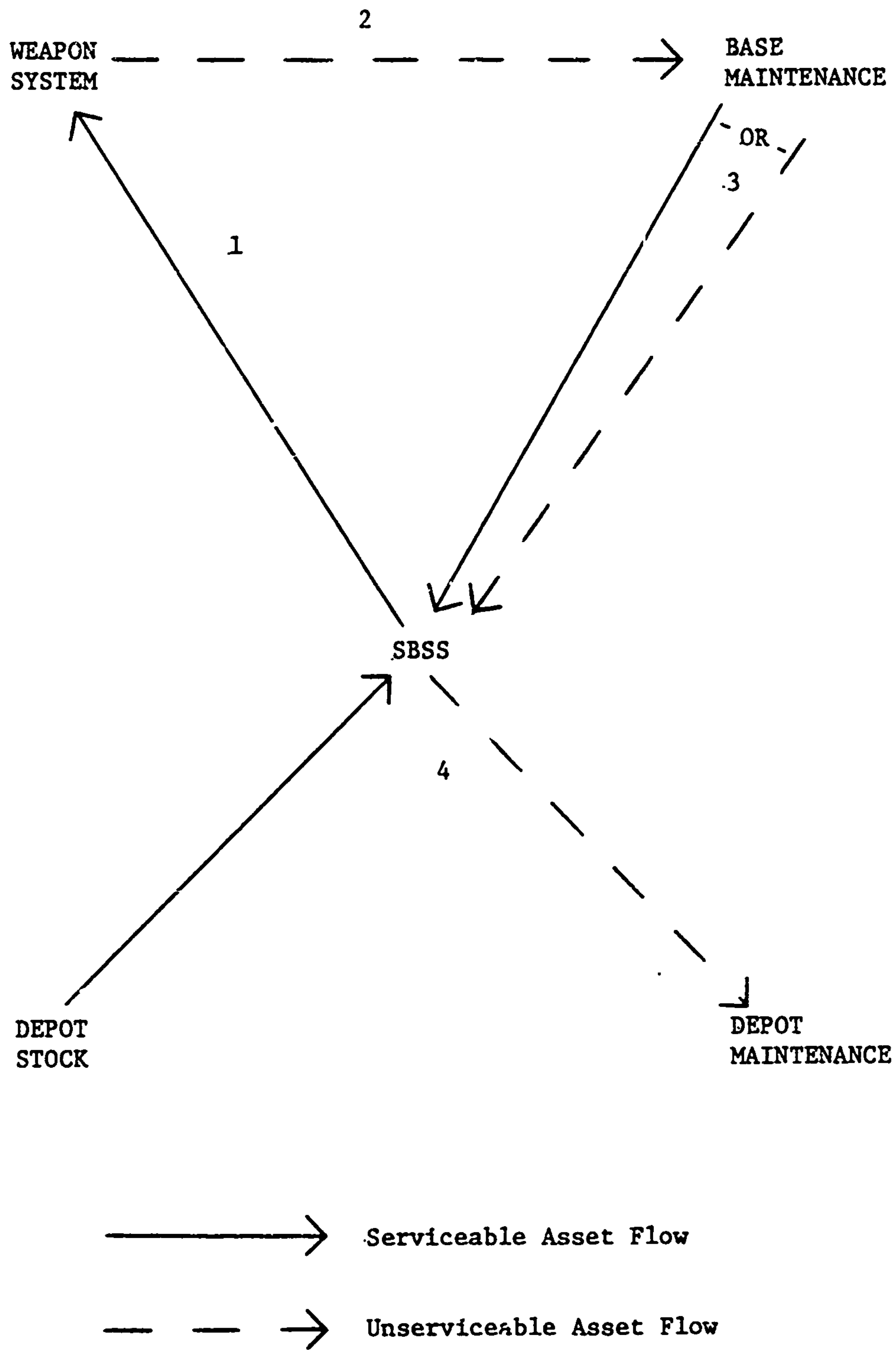

Figure 1. Positive Base Stock

If the item is repaired, it is turned-in to supply where it becomes part of the base stock, replacing the previously issued item (13:9). If the item is not base reparable, it is turned-in Not Reparable This Station (NRTS) to supply and shipped to depot (second echelon), or to disposal if the item can not be economically repaired at depot. Whether base repair is made or not, the time of turn-in to supply ends the repair cycle time. At time of turn-in for an unserviceable item, a requisition to the depot is made to bring the base stock level back to equilibrium for the original item issued (19:10).

Another set of actions occur when a serviceable item is not available in base stocks (see Figure 2). If the unserviceable item is repaired and reinstalled in the weapon system, which is a repair and return, no formal demand is made on supply. But, if the unserviceable item is not base reparable, then a demand is made on supply. Here, a requisition for a serviceable asset is sent to depot while the unserviceable is sent for repair. This act of sending a requisition to the depot when a demand is made and the base is unable to repair the unserviceable asset follows an (S-1,S) inventory policy (16:1).

(S-1,S) Inventory Policy. The (S-1,S) inventory policy is a continuous review inventory system where the total stock on-hand plus stock on-order minus the backorders always equals the spare stock level, S. The "S-1" is the reorder point and the "S" is the spare stock or demand level authorized for base stockage covering pipeline time and protection against stockouts (15:1). This inventory policy is normally used for reparable items which typically are expensive and have low demand rates. At the base level (SBSS), the RCDL inventory model replicates an (S-1,S) inventory policy and applies only to reparable

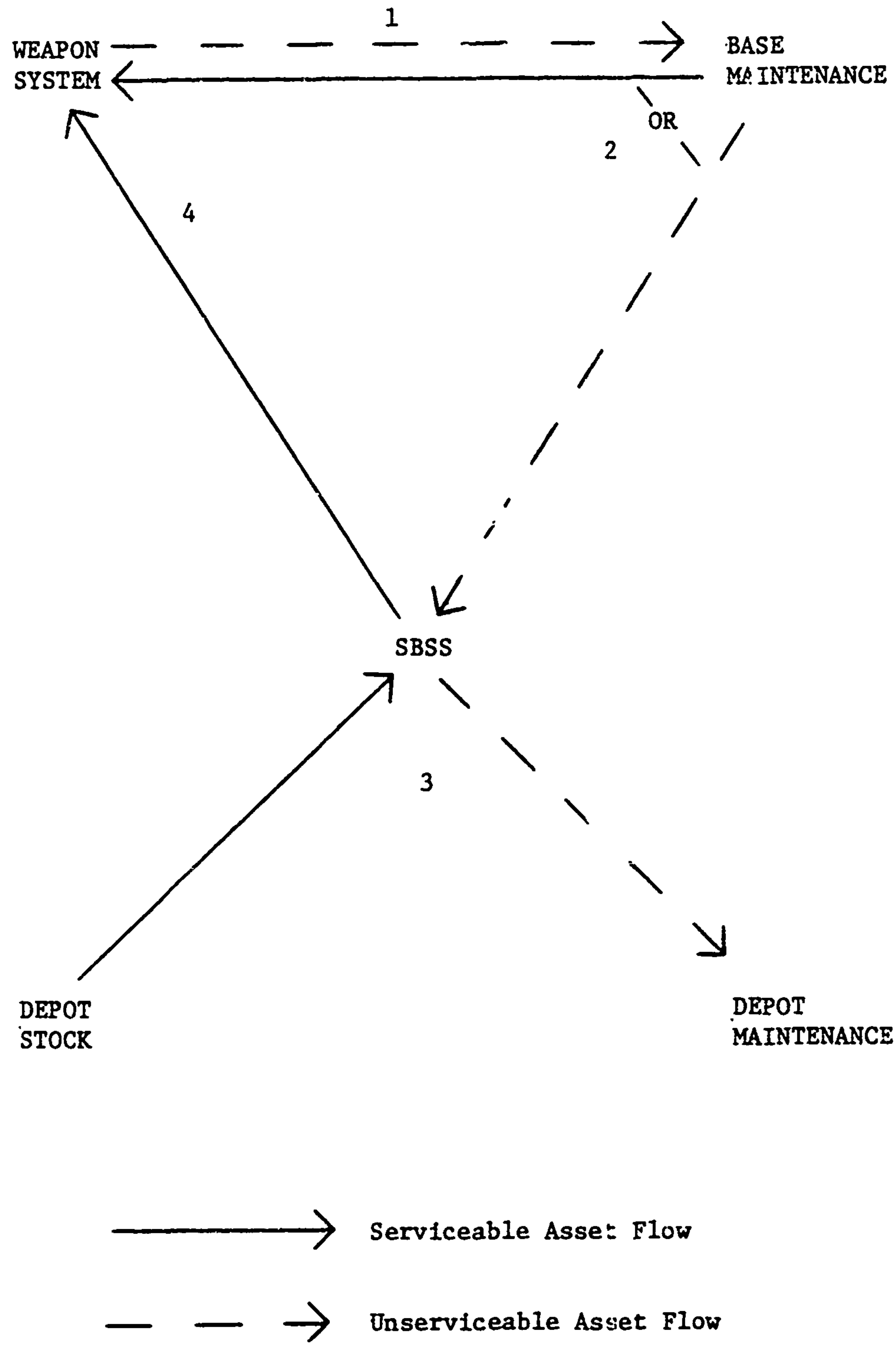

Figure 2. Zero Base Stock

items for which each customer is limited to ordering a quantity of one per request. This limitation ensures each item is controlled in the repair and replenishment pipelines.

<u>Repair Cycle Demand Level (RCDL) Model</u>. The RCDL model calculates spare stock, or repair cycle demand levels, tailored to individual base repair capabilities as a result of the application of the stockage policies used by base level managers. The RCDL model does not attempt to minimize or maximize any measure of supply performance. Simply, the stock levels are set to fill pipelines for both the time an item is in the repair and depot-to-base replenishment cycles, with a set safety quantity added for protection against stockouts (8:1). The quantity stocked, S, is given by:

$$S = RCQ + OSTQ + NCQ + SLQ + \text{Constant} \tag{1}$$

where RCQ = repair cycle quantity,

OSTQ = order and ship time quantity,

NCQ = NRTS/condemned quantity,

SLQ = safety level quantity,

Constant = .5 if the unit cost is greater than $750, or .9 if the unit coat is $750 or less (32:13).

RCQ and NCQ are the amount of stock necessary to fill the repair cycle pipeline while the OSTQ fills the depot-to-base replenishment pipeline (8:4). Prior to 1982, the NCQ was not used in calculating S. But as Weifenbach states:

> The on-base processing time charged to NRTS actions represents an interval or delay during which support must be provided out of base stocks. In this sense, it has an impact similar to that of repair cycle or pipeline time,...If this NRTS time were included in the

stock level computations (using the net repair cycle time, plus an 8-day pipeline time for NRTS), the aggregate demand level [S] would increase by 37 percent (33:44).

SLQ compensates for the fact the RCDL model assumes demand is constant or does not allow for demand variability (19:22). The model uses a normal distribution for computing SLQ with the square root of 3S equal to one standard deviation. This gives a three to one variance to mean ratio (19:4). The variance to mean ratio is a measure of dispersion (or variability) of demand about the average or mean demand. Here, the model is attempting to achieve an 84 percent service level—84 percent of the demands are filled from on-hand stocks while replenishment stock is in both the repair cycle and depot-to-base pipelines. This 84 percent service level is achieved with a C-factor (standard deviation) of one. To increase the service level, a higher C-factor is used (two or three). Each of the above quantities are given as follows:

$$RCQ = DDR \times PBR \times RCT1 \tag{2}$$

$$OSTQ = DDR \times (1 - PBR) \times OST \tag{3}$$

$$NCQ = DDR \times (1 - PBR) \times NCT \tag{4}$$

$$SLQ = C \times \sqrt{3 \times (RCQ + OSTQ + NCQ)} \tag{5}$$

where DDR (Daily Demand Rate) = $\dfrac{\text{cumulative recurring demands}}{\text{max(180, current - date of first demand)}}$

PBR (Percent Base Repair) = $\dfrac{\text{repaired units} \times 100}{\text{units repaired, NRTS, condemned}}$

$$\text{RCT1 (Repair Cycle Time)} = \frac{\Sigma\text{repair days}}{\text{number repaired}}$$

$$\text{NCT (NRTS/condemned Time)} = \frac{\Sigma\text{NRTS/condemned days}}{\text{number NRTS/condemned}}$$

$$\text{OST (Order and Ship Time)} = \frac{\Sigma\text{depot-base ship days}}{\text{number of receipts}}$$

Note: OST is the average elapsed time, in days, between the initiation and receipt of stock replenishment requisitions from depot,

C = C-factor or number of standard deviations to protect against stockouts i.e., 1, 2 or 3 (32:3-9,13).

When the computed RCT1 exceeds six days for selected "XD" items or nine days for all other items, six or nine days respectively is used in demand level computations (32:8). If the number of units is equal to or greater than four, the computed RCT1 will be used in lieu of the six and nine day standard. In addition, a RCT1 floor equal to the average RCT1 or no less than four days is programmatically applied to compensate for priority maintenance turnaround actions (20). For computing NCT, a constant six is used if the computed NCT is seven days or greater (32:4). As with RCT1, if the number of units is four or more the computed NCT is used in lieu of the six day criteria. In addition, a constant four days is used if the number of units in computing NCT is zero.

The SBSS also employs the Wilson EOQ model for determining stockage requirements for selected groups of items. Prior to 1984, only consumable items were managed under this concept. But as a result of a study performed by the AFLMC, "XF" items priced less than $750 with a PBR less than 50 percent now include an EOQ component in the RCDL model (8:2). The results of that study found aircraft availability and fill rates increase while overall workload decreases due to such a change.

The Retail Inventory Management and Stockage Policy Working Group requires all DOD units to set inventory policy, for consumable items only, based on minimizing total variable costs (7). The EOQ formula minimizes the sum of two variable costs: holding and ordering costs. Separate holding and ordering cost figures are used for local purchase and nonlocal purchase items (32:4a). The EOQ formula is integrated into the RCDL model, affecting approximately 65 percent of the "XF" items, revising the computation of S as follows:

$$S = EOQ + RCQ + OSTQ + NCQ + SLQ + .9 \tag{5}$$

where $EOQ = \dfrac{VC \times \sqrt{DDR \times 365 \times \text{unit cost}}}{\text{unit cost}}$,

VC is the constant used for applying order and holding costs (VC = 16.3 for local purchase and 8.3 for nonlocal purchase items), RCQ, OSTQ, NCQ and SLQ are computed the same as equation (1) (32:13-14).

Measuring the Effectiveness of Inventory Models

The RCDL model previously discussed predicts future item stockage based on pipeline quantities with an added safety quantity for protection against variability. Once this model produces a demand level, then some mechanism is required to grade its effectiveness. Many performance indicators exist measuring the effectiveness of inventory models translating spare stock to a common medium. Most of these measures view inventory processes as approximations of the poisson distribution using Palm's theorem as a basis (19:19).

Palm's Theorem. Palm developed a well-known queuing theorem which

states that if demand arrives according to a poisson process, then the number of units in resupply is also poisson for any arbitrary resupply distribution (18:5). The poisson state probability depends on the mean of the resupply distribution, not on the distribution itself. Feeney and Sherbrooke extend this theorem and apply it to inventory control theory by stating that the probability for x units in resupply is given by a poisson distribution with parameter λt ,i.e.,

$$p(x|\lambda t) = \frac{(\lambda t)^{x} e^{-\lambda t}}{x!} \qquad (7)$$

where x = units in resupply,

λ = mean rate of demand,

t = mean resupply time (15:3).

The Rand Corporation in 1976 further extended Palm's theorem by applying it to a dynamic or nonsteady state arrival process (19:19-21). Muckstadt found that applying a steady state inventory model to a dynamic environment, such as the onset of war, inaccurately estimates stockage requirements and supply system performance (23:1). Nonsteady state models allow for more items in repair during any surge in demand and fewer following the surge providing accurate measures of stockage and supply performance for a wide range of dynamically changing scenarios.

Most probabilistic inventory models, including those the Air Force currently uses, assume a stationary demand process (23:1). These models are valuable during periods of relatively stable flying activity typified by peacetime conditions. Hillestad and Carrillo comment that steady state models are:

widely applied to practical problems of inventory management. For many inventory systems including the Air Force Supply System in peacetime the assumption of steady state behavior is both convenient and adequate (18:1).

Whether or not Palm's theorem is applied in a steady or nonsteady state fashion, the underlying principle behind the concept for inventory systems is the poisson demand distribution.

Poisson Demand Distribution. Statistical distribution predictions for demand should follow three criteria: (1) accurately describe fluctuations in demand, (2) require simplicity in the data collection process, and (3) not be computationally burdensome (29:VII-2-6-7). The poisson distribution or variations within the poisson family are widely used in most inventory models generally meeting these three criteria. The poisson distribution is asymmetrical, skewed right, allowing an item with a low mean value such as one, to have a demand range from zero to five or more units. The higher the mean value, the more symmetrical the distribution becomes losing the skewed right pattern.

The poisson distribution is characterized by the parameter lambda. Lambda is the demands per unit of time and is the mean and variance of the distribution (19:5). The inverse of lambda is the mean of the exponential distribution and is considered in inventory theory as the mean time between arrivals or failures. Most aircraft avionics equipment is considered to follow exponential failure patterns giving rise to the use of the poisson distribution for reparable demands.

Feeney and Sherbrooke generalize demand as a compound poisson distribution, where the resupply distribution is arbitrary, again using Palm's theorem (15:2-7). The compound poisson distribution is characterized by batches of demand rather than single demands (simple or constant poisson), with the time between batches being the same for both

the compound and simple poisson (see Figure 3). The compound poisson distribution's main feature is the variance can exceed the mean; when the variance equals the mean (a variance to mean ratio of one), the compound poisson reduces to the simple poisson. The compound poisson distribution provides applicability for reparable item demand where high variability is sometimes seen. Feeney and Sherbrooke provide four possible explanations for this high variability:

(1) Sympathetic replacement of undetected malfunctions where a part may be found defective on one aircraft, so all aircraft are inspected replacing incipient failures.

(2) Initial wearout where some avionic parts fail shortly after installation.

(3) Damage during installation.

(4) Flying programs are usually correlated with the number of aircraft (15:6).

In the backorder case, which the SBSS typifies, the compound poisson probability of x demands in a time interval t is:

$$p(x) = \sum_{y=0}^{\infty} \frac{(\lambda t)^y \; e^{-\lambda t}}{y!} f^{y*}(x) \qquad (8)$$

where $f^{y*}(x)$ = y-fold convolution of f which is the probability that y customers place a total of x demands (28:4).

In the case where each customer places only one demand for an item, the y-fold convolution of f equals one, reducing equation (8) to the simple poisson density function (28:4).

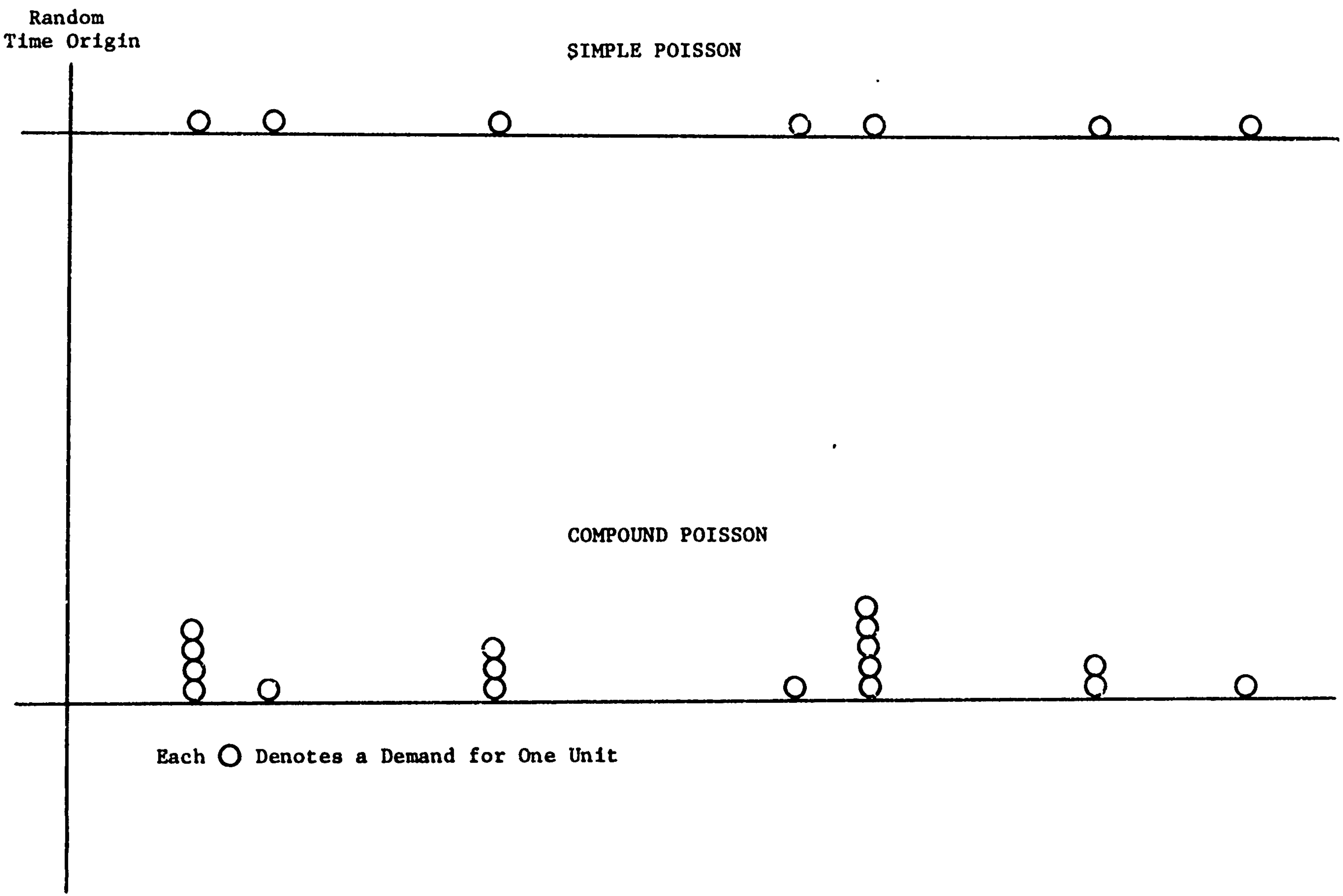

Figure 3. Comparison of Simple and Compound Poisson Demand (15:4)

Pyles mentions that most analyses use a poisson distribution with a variance to mean ratio of one, simple poisson (26:28). Pyles further points out that most models, and their associated demand data, do not provide the parameters for calculating a good estimate for the variance of each item. In an analysis performed on Air Force demand patterns, Mitchell, Rappold and Faulkner compare a geometric poisson model with that of a constant or simple poisson model stating:

> Although the former model [geometric poisson] has more theoretical appeal, the latter model [simple poisson] provides comparable predictions and because of its simplicity should provide significant advantages for implementation. Indeed, we showed that the constant-Poisson model is a reasonable one for all items regardless of unit cost (22:445).

Thus, the simple poisson distribution is used widely to describe demand and resupply probabilities inherent in most performance measures for solving inventory problems.

Performance Measures. All Department of Defense systems and agencies have standards or comparison measures to gauge the performance of the system or agency in question. Supply performance measures dealing with stockage fall into two categories: direct and operational (11:3-4). Such measures as fill rates, expected backorders and service levels are the more common direct performance measures used. Direct measures, as the title implies, are computed directly from actual stockage data and do not have as many intervening variables as do operational measures.

Two of the most common operational measures are Not Mission Capable (NMC) and Operationally Ready (OR) rates. Operational indicators measure weapon system availability and are a number of steps removed from supply stockage data.

All the measures previously mentioned (and many others), whether

they be direct or operational, can be applied to a poisson process by making a number of assumptions.

<u>Assumptions</u>. Brooks, Gillen and Lu describe four performance measures based on the following assumptions:

(1) One-for-one requisitioning. Whenever an item is demanded from supply, a replacement will eventually bring the stock level back to its original level. The replacement may either come from the base maintenance organization as a repaired item or from the depot in exchange for an unserviceable carcus.

(2) Backordering of unsatisfied demands. If a demand occurs and the item is in stock, then an issue will be made; otherwise, the demand is backordered.

(3) Markov property for demand. The number of demands within any given period of time is a poisson random variable and the number is independent of the number of demands in any other period.

(4) Stationarity of demand. The number of demands in a given time period is a poisson random variable whose probability distribution depends only on the length of the time period; identical time period lengths have the same probability. And there is no trend, seasonality or cyclical influence on demand.

(5) Independence of resupply time and demand. The demand for an asset and the time it takes to obtain it from depot or base maintenance will vary in a statistically independent manner. In addition, the decision to repair an item on base is independent of the number of demands in any given period (11:6-9).

Under the above assumptions, the number of demands follows a compound poisson probability distribution behaving according to the

(S-1,S) inventory policy (11:7-8). In addition to these assumptions, Hillestad and Carrillo emphasize that there must also be sufficient slack service capacity so no batching or wait exists for unserviceable assets arriving at repair facilities (18:32). Keeping these assumptions in mind, a number of authors comment on the merits of different performance measures.

Comments on Performance Measures. Sherbrooke evaluates different performance measures and states:

> Operational rates are not very flexible....it is difficult to give essentiality an ecomonic interpretation here. Operational rate also requires the analyst to supply a set of k values [number of aircraft at base] (27:7).

Sherbrooke concludes that a backorder criterion seems to be the most reasonable because the expected number of backorders provides good results with respect to other criteria, which is not conversely true. In addition, Sherbrooke mentions that the backorder performance measure is most often employed in inventory models.

Brooks, Gillen and Lu support Sherbrooke's conclusions in their study of alternative measures for supply performance by stating:

> Average backorders have an advantage over fill rate as a measure of performance, since we care not only whether backorders occur, but also how long they last. To take an extreme example, a supply system with zero fill rate will still be very good if each backorder lasts only three minutes. Fill rate gives, in this case, a very poor indication of performance. On the other hand, since the average number of backorders for this system will be low (unless demand rates are extraordinarily high), the average number of backorders will, in this case, be a good measure of performance (11:2-3).

Brooks, Gillen and Lu go on to say that operational rates have an advantage over backorders and fill rates because they directly measure supply's performance on operations (11:3-4). But operational rates also have a disadvantage in that they (in terms of NMC) do not distinguish

between one, two, three and so on number of aircraft not available. In addition, operational rates have a mathematical tractability problem. A mathematical prediction of average NMC due to supply (NMCS) aircraft requires more restrictive assumptions than do other more direct measures and is not as reliable in prediction as fill rate or average backorders.

Finally, Hillestad and Carrillo point out that those performance measures which attempt to predict the effect inventory has on a base's performance (operational type measures) are very "scenario dependent" (18:3). Such factors as the cannibalization policy, flying activity and a host of other variables must be programmed into any model using such measures. For this reason, and those comments previously stated, the expected backorder and fill rate measures are examined.

Expected Backorders. A backorder occurs when the number of demands exceed the spare stock available (13:13). Thus, a backorder (b) is given by:

$$b = d - s \tag{9}$$

where d = demand,

s = quantity stocked.

To measure average or expected backorders, the number of days an item is backordered over the course of a year is added up and divided by 365 (11:2). Another method giving almost the same result is to count the number of backorders in existence at a fixed time each day and average these numbers together over the course of a year. These methods are computationally tedious; therefore, by making the previously stated assumptions, the expected number of backorders for a particular item is:

$$E(b) = \sum_{d=s+1}^{\infty} (d-s)\, p(d|\lambda t) \tag{10}$$

where t (average resupply time) = (RCT x PBR) + [(1 - PBR)(OST + NCT)],

λ = DDR,

$p(d|\lambda t) = \dfrac{(\lambda t)^d \, e^{-\lambda t}}{d!}$ (13:13-14,23).

The expected number of backorders for all items is expressed as the summation, or by averaging, the expected backorders for the individual items (6:28).

Fill Rate. Fill rate is one performance measure used widely throughout the Air Force to evaluate the supply system (19:13). The fill rate is determined by taking the total number of units issued and dividing this by the total number of units demanded for a certain, fixed period of time (11:2). The quotient is thus the percentage of demands filled at the time of demand. Again using Palm's theorem, the fill rate (FR) for n number of items is given by:

$$FR = \frac{\text{Items Requested} - E(b)}{\text{Items Requested}} \tag{11}$$

where Items Requested = $\sum_{i=0}^{n} \sum_{d=0}^{\infty} (d*p(d|\lambda t))$ (7).

Reparable Models and Prior Studies

This section looks at the history of reparable item research. First, a synopsis of the evolution of reparable inventory models is outlined. Then, two prior sensitivity studies are reviewed showing the extent of past research on the parameters of RCT and PBR.

Evolution of Reparable Inventory Models. Palm first reported his conventional steady state theorem describing the poisson distribution of the number of units in a system in 1938 (12:14). The RCDL model, used by the SRSS, was developed in the early 1960's. The RCDL model treats each item independently calculating spare stock as a function of pipeline time. In addition, this model adds a safety stock quantity, according to a desired service level, using the normal distribution (19:21-22). At about this same time (1963), Hadley and Whitin applied Palm's theorem to reparable inventory systems, backorder and lost sales cases, using the poisson distribution to describe demand and resupply pipelines (15:2). Feeney and Sherbrooke in 1966 extended this research for a compound poisson arrival process by developing the Rand Base Stockage Model (12:14). This model optimizes minimum backorders over an entire range of items at the single echelon level. In 1968, Sherbrooke developed the Multi-Echelon Technique for Recoverable Item Control (METRIC) incorporating base level organizations and depots all in one model. METRIC provides a mechanism to compute optimum stocks for both echelons by minimizing total system backorders subject to a budget constraint. In 1973, Muckstadt went a step further by expanding METRIC, Mod-METRIC, to permit consideration for indentured relationships which had previously caused METRIC to buy too many low cost items. The Air Force also capitalized on METRIC by developing the LMI Availability Model which substituted military capability performance measures for the backorder minimization criteria. Again, Muchstadt (1976) developed another model called Consolidated Support Model extending the METRIC-type analysis to consider a three echelon supply system adding intermediate repair facilities. All of the above models assume a steady

state environment.

Not until 1972, when Gilbert and Faucett developed nonsteady state solutions for poisson demand and resupply systems, did transient models begin to appear (12:14). Demmy was the first in 1978 to model dynamic solutions for simple poisson failure processes in a two-echelon supply system. Hillestad and Carrillo extended this research in 1980 by deriving transient equations and applying these to many time dependent measures of system performance much like METRIC did with backorders in a steady state. Finally the Rand Corporation, using the previous research of nonsteady state equations, developed a dynamic, multi-echelon, multi-indentured model, Dyna-METRIC, translating logistics spares information into a number of performance measure outputs (17:22). Dyna-METRIC considers a three echelon inventory/repair system and is used extensively by the Air Force Logistics Command and other major commands in the Air Force.

Prior Sensitivity Studies. Very little research has been conducted in the area of base level sensitivity to repair cycle parameters. Weifenbach performed sensitivity testing with repair cycle time in 1966 using a RCDL model which excluded NCQ (33:45). These tests dealt with the effects variability in repair cycle times have on stock levels. Weifenbach states that substantial changes occur in repair cycle times for low demand items before a change in the stock level is seen (33:45). High demand items are quite sensitive to changes in repair cycle times, but the large volume of transactions minimizes the effect of short-term changes. Weifenbach concludes that aggregate stock levels are sensitive to hanges in repair cycle times; the stock levels increase as each day is added to the average repair cycle time for about five percent of the

items (33:45).

Bridges and Norris conducted regression analysis between PBR and operationally ready (OR) rates, at a single point in time, for 16 Air Force command units supporting a variety of weapon systems (9:17,50). The intent of this study was to see if PBR correlates to OR rates for measuring base self-sufficiency. This study did not analyze stockage effects or changes in the PBR in relationship to the OR rate at a single base. Bridges and Norris conclude that there is little relationship between PBR and OR rates under the methodology used (9:50).

The above studies provide little insight as to the degree RCT and PBR affect base self-sufficiency. However, these two studies did provide some background information relevant to this research effort. Weifenbach emphasizes the importance of NRTS pipeline time and comments on RCT sensitivity. While, Bridges and Norris help better define base self-sufficiency and its relationship to RCT and PBR.

Summary

This literature review highlights many factors which apply to this research effort. To begin, the RCDL model has changed in the last few years by adding two new elements used in calculating demand levels. The first is the integration of NCT as an added factor for computing the base repair pipeline quantity. The second element involves the addition of an EOQ component in the RCDL formula for selected "XF" items meeting a set cost and PBR criteria. These two elements require additional computation and screening for deriving spare stock, an essential parameter in most performance measures.

The selection of the performance measures are dependent upon many factors. These factors include the applicability of the poisson

distribution or a variate of it in describing reparable item demand, the extended use of Palm's theorem for steady and nonsteady state environments, and the evaluation of different performance measures. The next chapter deals with these issues further by laying the foundation for the methodology of this effort.

The evolution of reparable inventory theory concentrates primarily on multi-echelon systems where a number of bases are supported by higher tiers of supply such as wholesalers, depots and centralized repair facilities. Those models which did deal with base level supply operations did so by optimizing an objective function given some specified constraints. The evolutionary process for inventory theory did little for those pipeline models now in existence, such as the RCDL model. In addition, few studies concentrate on providing base managers the knowledge and tools with which to evaluate the effects of maximizing existing base resources. With this intent, and taking account of those intervening factors discussed, the sensitivity of RCT and PBR, two controllable base stockage parameters, are evaluated in the remaining portion of this report.

III. Methodology

Overview

The prior chapter introduced some considerations impacting the methology of this study. This chapter further discusses these considerations deriving the selected performance measures and assumptions under which this research is conducted. Once the performance measures and assumptions are derived, the experimental design is formulated such that the two basic investigative questions are answered over a wide range for RCT and PBR. The data base is briefly outlined giving the usage for each data element and its relationship to the model. Then, the model itself is examined showing how a demand level is obtained for each item and the method for calculating the selected performance measures. Finally, the model is validated and verified insuring RCDL and performance indicator calculations, and parameter changes are accurately replicated.

Selected Performance Measures and Assumptions

To assure the results directly relate to changes in RCT and PBR, at the same time represent the fluctuations in a SBSS reparable system, the performance measures selected are expected backorders and fill rate using the simple poisson distribution. The expected backorder measure accounts for the length of a backorder while fill rate provides the probability stock is on-hand. These performance indicators are direct measures using spare stock, in this case demand levels derived from RCT and PBR, as an input parameter. Both measures are widely used and do not require additional restrictive assumptions characteristic of operational performance measures. For this study, the accuracy of a

direct measure is of more concern than operationalizing the model to include "scenario dependent" factors such as cannibalization, flying activity and lateral support considerations.

The simple poisson distribution is used for a number of reasons. This distribution is widely accepted and used in solving inventory problems, especially those involving reparable items. The simple poisson distribution requires only one parameter, lambda or the mean, and is characterized by a variance to mean ratio of one. This ratio overstates performance since stockage is calculated at a three to one ratio (19:59-60). However, the emphasis in this study is on the change in the performance measure values rather than the values themselves. The simple poisson also translates into most modeling languages and is not mathematically burdensome. The compound poisson distribution or variations of this distribution are also frequently used where customers may order batches of an item at any particular time. For the SBSS, customers are limited to ordering a quantity of one per request even though the system may at times "act" as if compound demands exist. This study reduces the compound poisson distribution to the simple poisson as explained by Sherbrooke in his report on compound poisson processes (28:4).

The model is built based on steady state equations versus the more recently developed dynamic equations. Using a steady state assumption is computationally advantageous over nonsteady state, but is only applicable and accurate for stable environments such as normal peacetime flying. For the purposes of this study, peacetime activity and its associated data is appropriate. The model does not attempt to measure the effect inventory has on base performance in a dynamic environment,

but assess the effects base resources have on self-sufficiency keeping the environment constant. A steady state assumption seems appropriate since during peacetime the relationship between the SBSS and depots is a "pull" type relationship (24:18-19). The SBSS determines its item requirements and draws or pulls replenishment stock from the depots. During times of increased hostilities, depots begin to "push" stock to the field before demand levels are adjusted to compensate for the increased activity. Since the focus of this study is on the SBSS RCDL model, actual demand levels generated from the model are of more interest in evaluating base self-sufficiency than accounting for the effects of a dynamic environment on inventory. Many authors and models use steady state equations because they are adequate, accurate and convenient for solving inventory problems within this environmental scope (18:1).

Finally, one other performance measure is included that being the dollar value of stock (stockage cost). This measure is obtained by multiplying each item's demand level by its unit cost giving the value of the stock for each item at the base in question. The value of all items stocked at a base is the summation of each item's stockage cost. This measure sheds light on the savings produced by changing the PBR and RCT base self-sufficiency parameters. Overall, the three selected performance measures gauge a range of base self-sufficiency effectiveness by determining the time weighted average number of backorders, the probability a demand is filled, and the cost of stock.

Experimental Design

The experimental design reflects four main purposes. One is to see the incremental effects on the performance measures for a range of

changes in RCT and PBR looking in the improvement direction. Second is to see the aggregate effects when both parameters change. Third is to select changes in RCT and PBR which are realistically controllable at base level and beyond a base's control. Base level managers possess only a degree of control over these parameters. Other factors beyond the base's control also influence these parameters i.e., coding an item for depot repair only, not authorizing additional or special repair equipment for use at individual bases, and restricting personnel expertise and specialities. And finally, the fourth purpose is to insure the experimental design answers the investigative questions posed.

The experimental design is broken into two segments corresponding to the two investigative questions. These two segments are changes in RCT and PBR. The RCT parameter is further divided into two subsegments, one being the change in the average time an item is repaired (labeled RCT1) and the other being the change in the average time an item is in the repair cycle system, but not repaired (NCT). The model first calculates the performance measure values for the actual RCT and PBR providing the base point for the sensitivity analysis. From here, the analysis is viewed as a series of sensitivity runs. Each run calculates new performance measure values as incremental changes are made in the parameters. The experimental design is illustrated in Table I.

Runs 1 through 19 change only one parameter at a time keeping the others constant at their actual level. Then, eight additional sensitivity runs (20 through 27) are processed measuring the aggregate effect on the performance measures when PBR and RCT1 both increase. The objective here is to observe the effects on the performance measures

TABLE I

Experimental Design

Sensitivity Runs	PBR	RCT1	NCT
Actual	X	X	X
1	+.01		
2	+.02		
3	+.05		
4	+.10		
5	+.20		
6	+.30		
7	+.40		
8	+.50		
9		- .1	
10		- .2	
11		- .5	
12		-1.0	
13		-2.0	
14		-3.0	
15			- .1
16			- .2
17			- .5
18			-1.0
19			-1.5
20	+.01	+ .1	
21	+.02	+ .2	
22	+.05	+ .5	
23	+.10	+1.0	
24	+.20	+1.0	
25	+.30	+1.0	
26	+.40	+1.0	
27	+.50	+1.0	

by increasing PBR when such a change might adjust RCT1 upward. It is assumed RCT1 does not increase any higher than one day, without subsequent equipment and manpower additions, conpensating for the increase in the number of base repairs.

The experimental design answers the questions of how much selected performance measures change by decreasing RCT and increasing PBR. In addition, the design differentiates the relationship in the performance measures for small and large changes over a wide range. And finally, the design evaluates the resultant effects of driving RCT1 up caused by increasing the percentage of repairs made on base.

Data Base

The Air Force Logistics Management Center collects reparable item data for 12 Air Force bases worldwide. RAF Upper Heyford, England is selected from those 12 bases as the sample base for this study. RAF Upper Heyford supports a wing of F111E aircraft, EF111 electronic countermeasure aircraft, and a NATO communications network (14:26,195). RAF Upper Heyford's support of avionics, aircraft and test station equipment, and electronic communications gear provides a large and varying reparable asset data base. In addition, other researchers frequently use RAF Upper Heyford's data base in their studies including Shields and Blazer just to name two (7).

Before applying this data to the model, it is necessary to explain its relationship and importance to the study:

Routing Identifier (RI) code: Every depot or source of supply is assigned a RI code and each item (line item) is given a RI code according to its source of supply. In the model, this code is used to obtain the average order and ship time (OST) originating from a study

performed by Blazer in 1983 (9).

Exception repair days: Occasionally an item has an exceptionally high RCT due to uncontrollable circumstances. When this occurs, base managers may load a reasonable RCT in lieu of the actual so as not to distort the overall base RCT. If exception repair days are loaded, the model exempts the item from the analysis since sensitivity on an inaccurate value distorts results whether the actual or loaded value is used.

Expendability Recoverability Reparability Cost (ERRC) code and unit cost: These two elements identify those items using the EOQ component of the RCDL model. The unit cost is used in calculating EOQ and the ERRC code also determine RCT1/NCT standards if they apply.

Cumulative Recurring Demands (CRD) and Date of First Demand (DOFD): The Daily Demand Rate (DDR) is derived from these data elements as explained by equations (2) through (5).

Total repair and NRTS days, and total number of repair and NRTS items: These data elements are used to calculate RCT1, NCT and PBR.

The Model

Model Language. Fortran 77 is the selected language by which the model is formulated. Fortran 77 is preferred over other analytical or simulation languages for a number of reasons. First is the analytical capability of the language in performing quantitative or scientific-type problems (1:16). At the same time, the language handles large informational processing requirements. Second, Fortran 77 is a popular language used or available on most systems; a number of AFIT computer systems already have Fortran 77 loaded. For this study, the VAX/VMS computer system is used because of its improved Fortran compiler and

increased data storage capability. In conjunction with this, Fortran 77 is readily available and adaptable to microcomputers used at base level where a model can be replicated and sent out to the field for base level use. Simulation languages are not as widely used or available at base level for either centralized or microcomputer systems. In addition, simulation languages usually are not adaptable to functional use in accepting raw data, despite being easier to program for modeling. Kutzke and Turner further explain the differences between analytical and simulation languages by stating:

> The mathematical processes [analytical models] are so exacting that for a given set of input parameters only one set of outputs is possible. This is in contrast to a sampling study using a simulation model. In simulation, a random number generator would produce different output results. Several runs would have to be completed for each cell [test]...to reach an answer for each cell. If a truly random sampling was used, there is a very high probability that simulation would come close to but never duplicate the same answer for each cell, no matter how many simulations were run on that cell. The significance of using the analytical model in the multiple case study mode is that it is much less time consuming (19:55).

Synopsis of the Model. The model · composed of several major functions for processing reparable item data (see Figure 4). Initially, the model feeds in all the data calculating the actual RCT and PBR for the base and computing the performance measures (PM) for each item. Expected backorders and stockage cost are summed, and the fill rate is derived as shown in equation (11), providing the base point for the sensitivity analysis. The summation of the probabilities for computing expected backorders for each item is completed when the probability reaches the .0001 level (refer to equation 10). The model then outputs the actual RCT, PBR and performance measure values for the base and prompts for the new parameter changes.

The new parameter changes are subtracted from the actual values

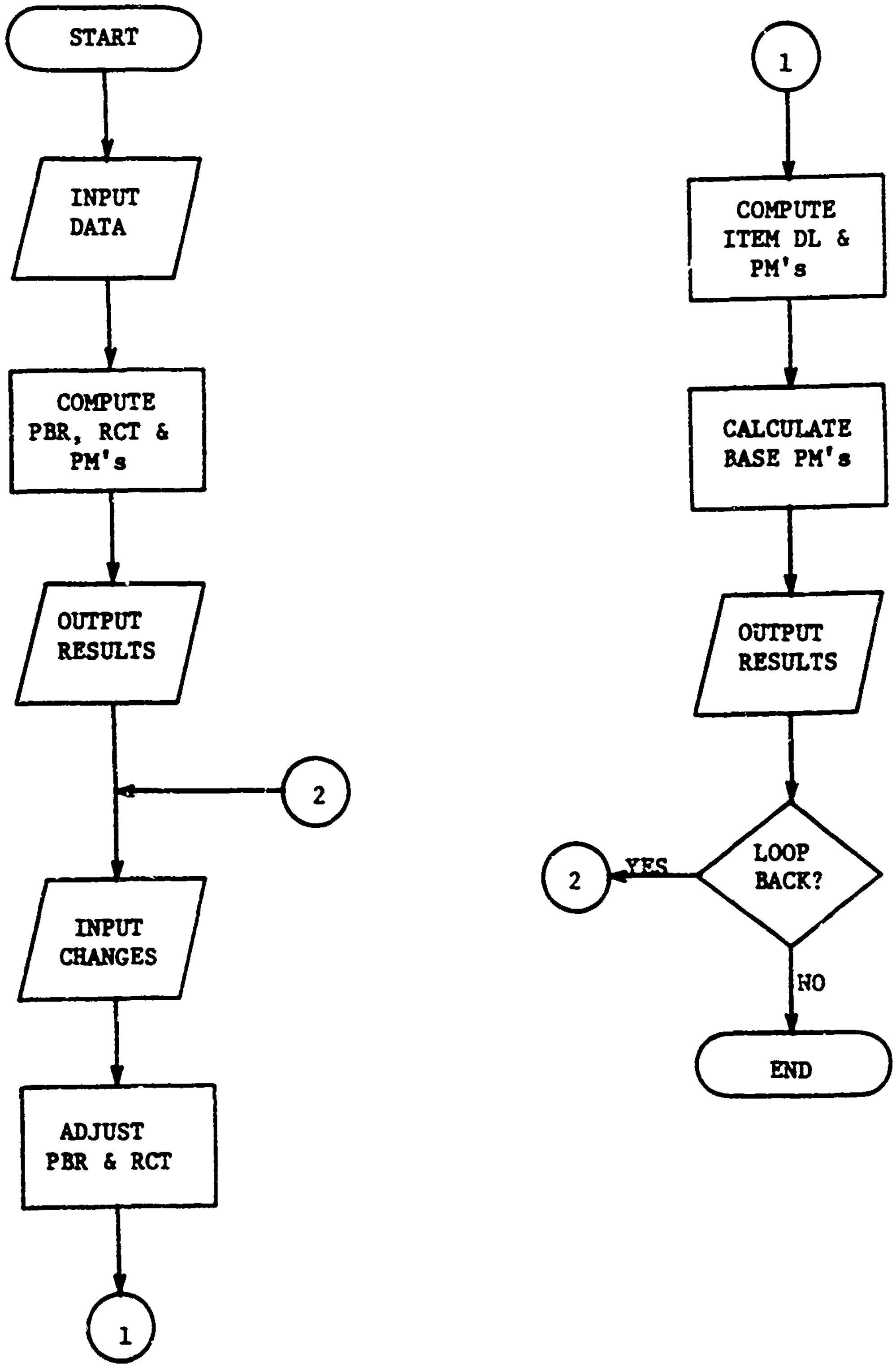

Figure 4. Model Design

giving the incremental amount by which each item's RCT and/or PBR is adjusted. RCT is not dropped below one since the RCDL model is designed so each item in the repair cycle accumulates at least one day whether or not less time is taken. Also, PBR is not adjusted above .99 for any particular item. If the incremental adjustment should increase PBR above .99, that amount which exceeds the .99 level is accumulated for all occurrences. This accumulated total is then distributed equally to those items not at the .99 level. This algorithm ensures the full PBR change is taken and prevents the model from exceeding the maximum PBR level. Once the RCT and PBR are adjusted for each item, a demand level is calculated complying with RCDL conventions.

From the demand levels, the performance measures are computed for the system under the changed parameter conditions. The new expected backorder value is divided by the actual giving a percentage change, while the new fill rate and stockage cost values are subtracted from the actual values giving their differences. The new performance measure values and their percentage change/differences are output and a prompt is then given allowing the user to terminate the program or loop back to input a new set of parameter changes.

Validation and Verification

The validation and verification process is conducted on three critical functions of the model to insure the output produced is consistent with that of the SBSS. The tests compare manual calculations against those computed by the model for five different scenarios. These scenarios vary the ERRC code, unit cost and the sensitivity parameters of PBR and RCT. PBR and RCT range from 0 to .99 and 1 to 10, respectively, covering the spectrum of possible circumstances. The

first series of tests deals with the computation of demand levels. The demand level differences never exceed .004 indicating the model is accurately calculating these values. The small differences are attributed to the limitations and rounding errors associated with manual computations performed on a calculator. One other demand level test is performed comparing model results with two examples exhibited in AFM 67-1 (32:13). The computed demand levels for the examples in AFM 67-1 are 2.6926 and 3.0926. The model produces demand levels of 2.6929 and 3.0929, respectively, further providing evidence the model accurately replicates demand level calculations given by the RCDL model.

The second series of tests is designed to insure the algorithm for making the parameter changes operate properly by increasing PBR ten percent and decreasing RCT one day. No differences between the model and manual calculations for any of the 15 separate runs are seen. As a further test, an additional run is made requiring the algorithm to iterate at least three times for a selected PBR change. Again, no error is detected validating this critical function of the model.

The final series of tests compares the output from the model, expected backorders and fill rate, with that computed manually using a set of poisson distribution tables giving probabilities to the .0001 accuracy level. Out of 15 tests, no difference greater than .0026 is seen. The small differences appearing are attributed to manual rounding errors and the difference in the degree of accuracy between the poisson tables and the computer model. The model computes to eleven decimal places while the poisson tables are limited to four places.

Overall, the tests confirm the model is working properly and replicating the SBSS accurately. With this in mind, the next step is to process actual data from RAF Upper Heyford and report the findings.

IV. Results

Overview

The results of this study are presented in both tabular and graphic form. The model itself is presented in the Appendix. Tables II and III portray the output results in the form outlined by the experimental design. Figures 5, 6 and 7 graph the output results for expected backorders, fill rate and stockage cost, respectively. Linearity is first discussed since the graphic results indicate a straight line relationship between the parameters and the performance measures. Next, the primary objective of this study is analyzed looking at the sensitivity of the base self-sufficiency parameters of PBR and RCT on the performance measures. Included in this analysis is an examination of the effects in increasing PBR and RCT1 in conjunction with one another. Finally, the results are summarized leading to the conclusions and recommendations in the following and final chapter.

Linearity

With one exception, an apparent linear relationship exists between the changes in the parameters and the performance measures. The exception occurs when PBR is adjusted upward by 40 percent or to a level of .7838326. This exception is most visible for the expected backorder and fill rate performance measures. The rate of decline for expected backorders is fairly steady until a large increase is seen at the point in question. For the fill rate, a steady increase occurs followed by a sharp drop. In both of these cases the trend is adverse. Little effect is seen on stockage cost at this point.

TABLE II

Expected Backorder and Fill Rate Results

Run	Parameter	Para Value	E(b)	% Change	Fill Rt	FR Diff
			** PBR Parameter **			
0	Base PBR	.3838326	67.00029		97.17994	
1	PBR +.01	.3938326	66.56158	.6547928	97.19840	.0184631
2	PBR +.02	.4033326	65.83290	1.742363	97.22907	.0491333
3	PBR +.05	.4338326	64.47546	3.768390	97.28621	.1062698
4	PBR +.10	.4838326	62.49477	6.724626	97.36957	.1896286
5	PBR +.20	.5838326	56.94069	15.01427	97.60335	.4234085
6	PBR +.30	.6838326	53.75068	19.77545	97.73762	.5576782
7	PBR +.40	.7838326	58.02083	13.40212	97.55788	.3779449
8	PBR +.50	.8838326	51.53395	23.08400	97.83092	.6509857
			** RCT1 Parameter **			
0	Base RCT1	4.203321	67.00029		97.17994	
9	RCT1 -.1	4.103321	66.62749	.5564213	97.19563	.0156936
10	RCT1 -.2	4.003321	66.40423	.8896410	97.20502	.0250778
11	RCT1 -.5	3.703321	65.78980	1.806688	97.23089	.0594909
12	RCT1 -1.	3.203321	64.26292	4.085600	97.29515	.1152115
13	RCT1 -2.	2.203321	62.43654	6.811542	97.37202	.1920853
14	RCT1 -3.	1.203321	59.23136	11.59537	97.50693	.3269852

TABLE II Continued

Expected Backorder and Fill Rate Results

Run	Parameter	Para Value	E(b)	% Change	Fill Rt	FR Diff
			** NCT Parameter **			
0	Base NCT	2.803577	67.00029		97.17994	
15	NCT -.10	2.703577	66.95663	.0651657	97.18178	.0018336
16	NCT -.20	2.603577	66.82973	.2545714	97.18711	.0071716
17	NCT -.50	2.303577	66.61694	.5721688	97.19608	.0161361
18	NCT -1.0	1.803577	66.76328	.3537416	97.18992	.0097924
19	NCT -1.5	1.303577	66.26729	1.094025	97.21708	.0384564
			** PBR/RCT1 Parameters **			
0	Base PBR Base RCT1	.3838326 4.203321	67.00029		97.17994	
20	PBR +.01 RCT1 +.1	.3938326 4.303321	67.00055	-.0003814	97.17992	-.0000525
21	PBR +.02 RCT1 +.2	.4038326 4.403321	66.62529	.5596995	97.19572	.0157852
22	PBR +.05 RCT1 +.5	.4338326 4.703321	65.51952	2.210087	97.24226	.0623245
23	PBR +.10 RCT1 +1.	.4838326 5.203321	65.08838	2.853584	97.26041	.0804672
24	PBR +.20 RCT1 +1.	.5838326 5.203321	60.21391	10.12889	97.46558	.2856445
25	PBR +.30 RCT1 +1.	.6838326 5.203321	57.08383	14.80062	97.59733	.4173839
26	PBR +.40 RCT1 +1.	.7838326 5.203321	62.26410	7.068902	97.37928	.1993406
27	PBR +.50 RCT1 +1.	.8838326 5.203321	55.36253	17.36971	97.66978	.4898376

TABLE III

Stockage Cost Results

Run	Parameter	Para Value	D/L	Cost	Savings
		** PBR Parameter **			
0	Base PBR	.3838326	9572	51,593,392	
1	PBR +.01	.3938326	9470	51,011,988	581,404
2	PBR +.02	.4038326	9418	50,365,936	1,227,456
3	PBR +.05	.4338326	9188	48,757,744	2,835,648
4	PBR +.10	.4838326	8801	46,434,254	5,159,138
5	PBR +.20	.5838326	8109	43,279,296	8,314,096
6	PBR +.30	.6838326	7374	38,942,172	12,651,220
7	PBR +.40	.7838326	5506	35,014,108	16,579,284
8	PBR +.50	.8838326	4781	31,143,284	20,450,108
		** RCT1 Parameter **			
0	Base RCT1	4.203321	9572	51,593,392	
9	RCT1 -.1	4.103321	9571	51,593,276	116
10	RCT1 -.2	4.003321	9567	51,538,220	55,172
11	RCT1 -.5	3.703321	9556	51,502,632	90,760
12	RCT1 -1.	3.203321	9553	51,415,252	178,140
13	RCT1 -2.	2.203321	9536	51,155,380	438,012
14	RCT1 -3.	1.203321	9524	51,047,756	545,636

TABLE III Continued

Stockage Cost Results

Run	Parameter	Para Value	D/L	Cost	Savings
		** NCT Parameter **			
0	Base NCT	2.803577	9572	51,593,392	
15	NCT -.10	2.703577	9550	51,504,264	89,128
16	NCT -.20	2.603577	9541	51,435,416	157,976
17	NCT -.50	2.303577	9511	51,316,048	277,344
18	NCT -1.0	1.803577	9460	51,152,184	441,208
19	NCT -1.5	1.303577	9438	50,964,752	628,640
		** PBR/RCT1 Parameters **			
0	Base PBR Base RCT1	.3838326 4.203321	9572	51,593,392	
20	PBR +.01 RCT1 +.1	.3938326 4.303321	9490	51,011,988	581,404
21	PBR +.02 RCT1 +.2	.4038326 4.403321	9420	50,371,776	1,221,613
22	PBR +.05 RCT1 +.5	.4338326 4.703321	9214	48,930,840	2,662,552
23	PBR +.10 RCT1 +1.	.4838326 5.203321	8659	47,365,908	4,227,484
24	PBR +.20 RCT1 +1.	.5838326 5.203321	[illegible]	44,108,244	7,485,148
25	PBR +.30 RCT1 +1.	.6838326 5.203321	7456	39,950,204	11,643,188
26	PBR + [illegible] RC[illegible]	.7838326 5.203321	5603	35,901,884	15,691,508
27	PBR +.50 RCT1 +1.	.8838326 5.203321	4901	32,420,474	19,172,918

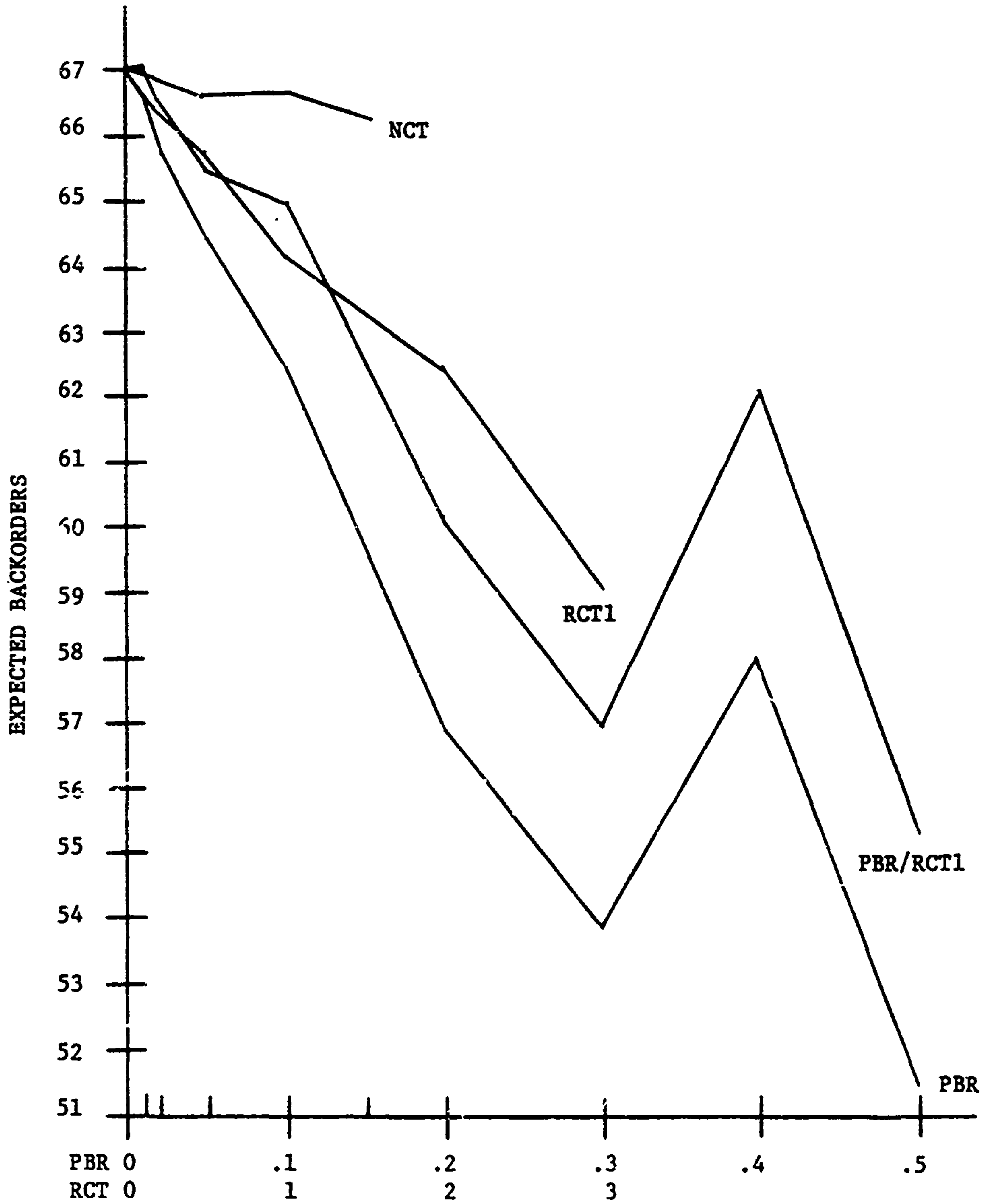

Figure 5. Expected Backorders

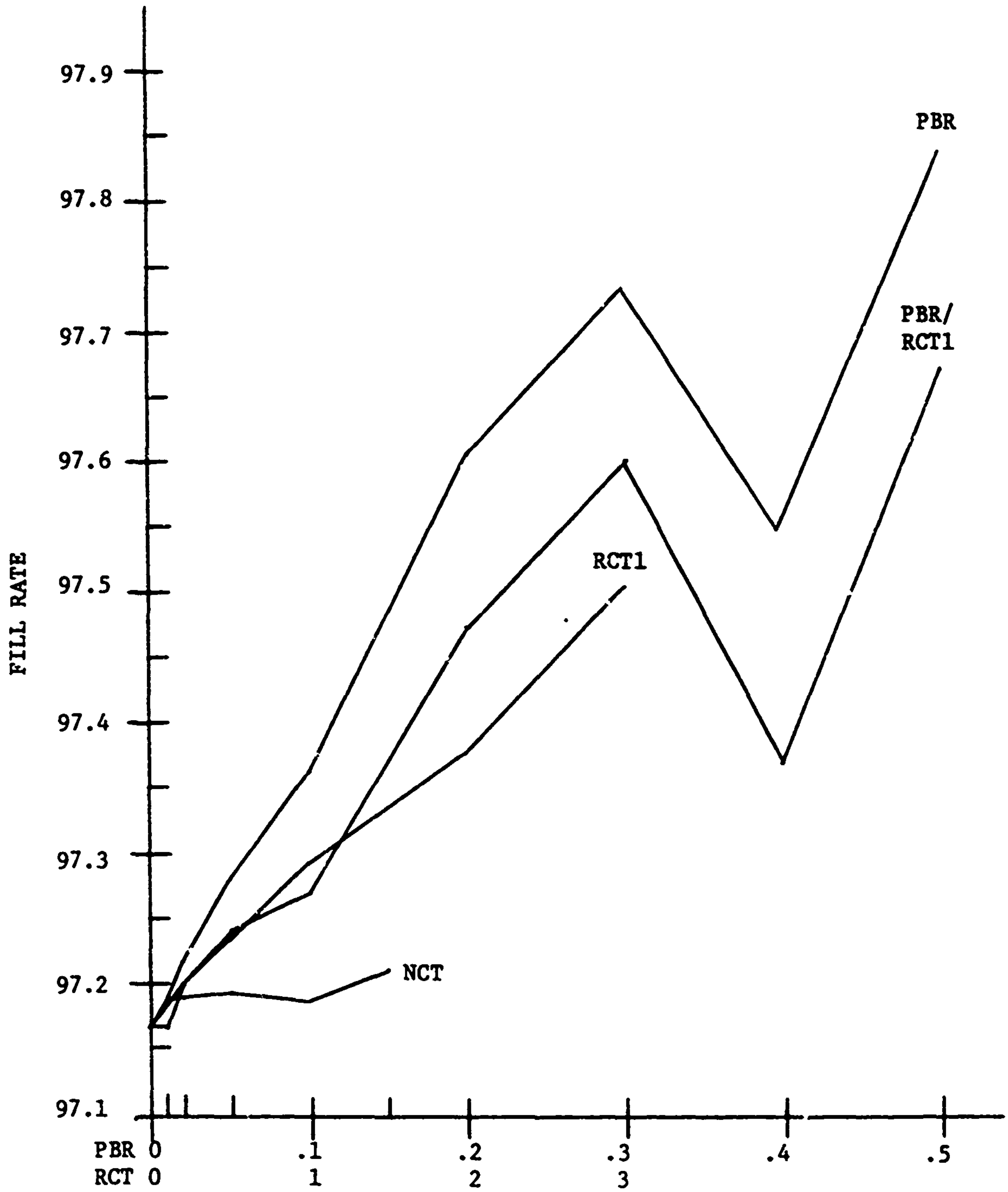

Figure 6. Fill Rate

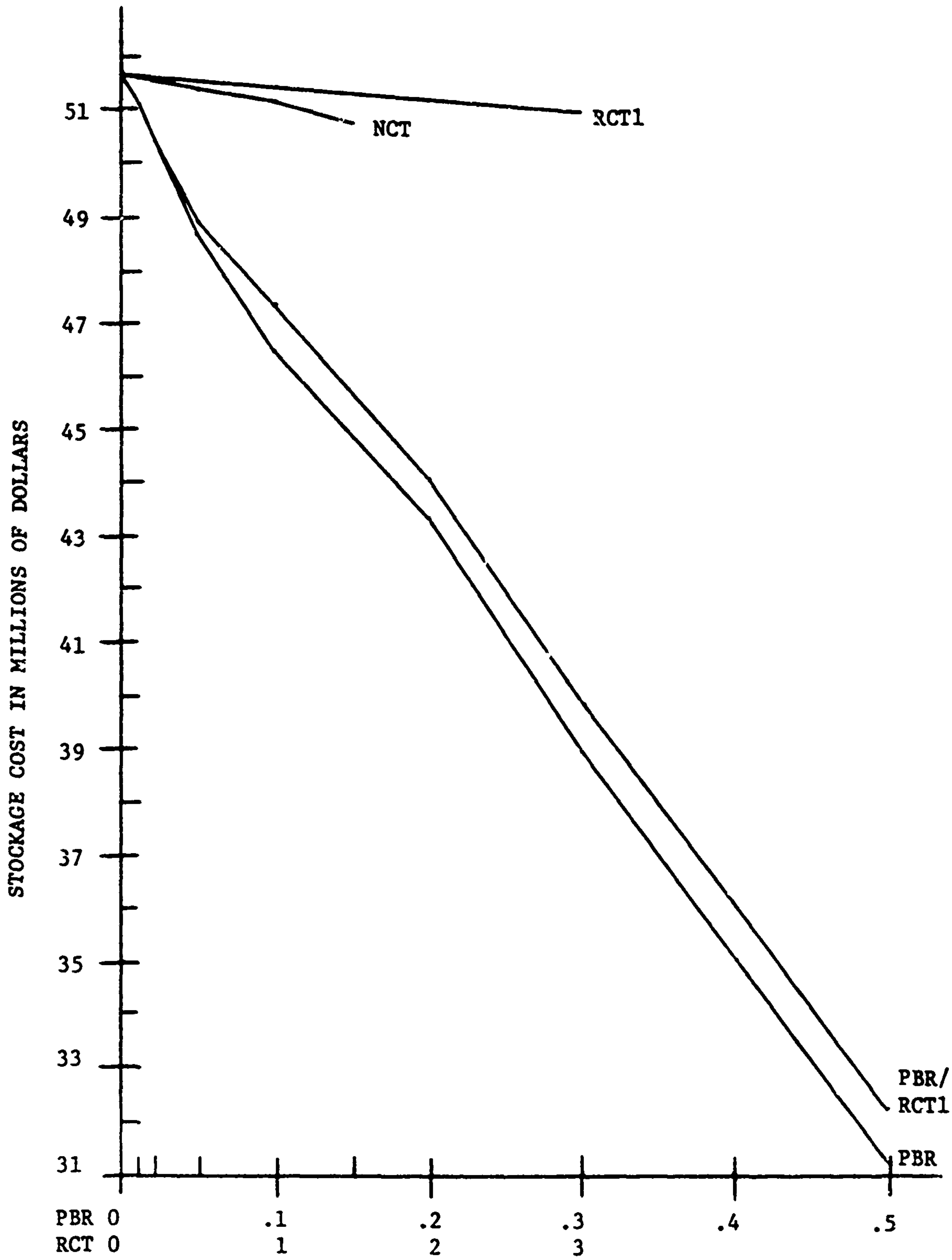

Figure 7. Stockage Cost

The initial conclusion one might reach is that a bad "XF" record exists characterized by a large EOQ component in the demand level. As PBR increases, the PBR for the "bad" record hits 50 percent or greater thus erasing a large portion of the total system demand level which in turn adversely affects the two performance measures. The total system demand level drops from 7374 to 5506, a loss of 1868 items, between a PBR of .6838326 (+.30) and .7838326 (+.40). After further investigation, the point where the bulk of the drop occurs is narrowed between a PBR of .7705 and .7710. Here, the demand level drops by 963 items. Prior to this point, the average drop in demand level for each 10 percent increase in PBR is 721. The entire data file is next screened to see if any bad records exist. None are found, but what is evident is a large number of "XF" records with a zero PBR. From this it is deduced these records are incremented to a PBR of 50 percent or greater exceeding the EOQ criteria. The model's algorithm, for adjusting PBR, increases each item's PBR by 50 percent, except those reaching the .99 cap, when a change of +.3867 is made. This occurs because more items are capped at 99 percent at this point leaving their incremental PBR adjustment for those not capped, as explained in chapter 3. Thus, the associated EOQ component for these records are no longer added into the demand level as before. There are 533 "XF" line items meeting the EOQ criteria with an initial zero PBR. These line items have 946 items in the EOQ portion of their demand levels explaining the large drop in total system demand level causing the adverse affect in expected backorders and fill rate. The remaining 17 items (963 minus 946) drop off through normal attrition because of the increase in PBR. The stockage cost performance measure is relatively unaffected because

the unit cost for these items is small, as one would expect for an item with no base repair. The total EOQ stockage cost for these items is $112,269.60 giving an average unit cost of $118.68 as compared to the average unit cost of $5390.03 for all items.

Since the "linear exception" (now referred to as the EOQ deviation) is validated, a simple linear regression analysis is performed on those sensitivity runs which vary only one parameter (1 thru 19). The strength of linearity is measured by the Pearson product moment coefficient of correlation r, commonly referred to as the correlation coefficient or r-factor. McClave and Benson define the r-factor as a quantitative measure of the strength of the linear relationship between an independent x variable and dependent y variable (21:418). In this study, the independent variables are the PBR and RCT parameters while the dependent variables are the respective individual performance measures. The r-factor is a scaleless measure between the values of -1 and 1. A value near or equal to zero implies little or no linear relationship. The closer the r-factor is to -1 or 1, the stronger the linear relationship. Negative values imply an inverse relationship between x and y.

A 95 percent confidence level is selected as the level of reliability for testing the r-factor. This reliability level or significance of the r-factor is measured by an r-test value extracted from a table using the sample size and significance level desired (34:3-10,3-18). If the absolute value of the r-factor exceeds the r-test value, then it is correct to assume the r-factor is not due to chance variation alone, with a 95 percent degree of certainty. Table IV provides the results of the linear regression analysis:

TABLE IV

Linearity Test

		***** r-factor Coeffieients ****		
Parameter	r-test	E(b)	Fill Rate	Cost
PBR (partial)	.755	-.9966458	.9966479	-.996621
PBR (all)	.666	-.926713	.9267286	-.9989412
RCT1	.755	.9965085	-.9965079	.9918073
NCT	.811	.8891066	-.8391614	.991958

Two different sets of data points are used to test PBR linearity. Linearity is first tested on only those data pointr from the actual base PBR to the data point prior to the EOQ deviation (identified as PBR partial). Then, all data points are regressed to see the linearity effect caused by the EOQ deviation (PBR all). As shown in Table IV, all parameters exceed the r-test threshold values including those containing the EOQ deviation. This indicates the relationship between the parameters and the performance measures are linear with a 95 percent degree of confidence.

From Table IV, three interesting observations are made. First and most obvious, the effects of the EOQ deviation did lower the r-factor, but not enough to fail the r-test. Thus, the EOQ deviation disrupts the trend, but not enough to cast sufficient doubt about the linear relationship between PBR and the performance measures. Second, the absolute value of the r-factor coefficients for expected backorders and fill rate are nearly equal, within each parameter, and carry an opposite sign. This shows expected backorders and fill rate are inversely related and change correspondingly. This is as expected since the fill

rate is a function of expected backorders. A decline in expected backorders increases the fill rate by an equivalent percentage amount according to the fill rate equation. Third, the NCT r-factors for expected backorders and fill rate are observably lower than the other r-factors. The other r-factors (except those depicting the EOQ deviation previously addressed) are in the range from just below .99 to just below 1, while the NCT r-factors in question are both well below .9. This is probably due to the short range tested for NCT, 2.803577 to 1.303577, and the smaller number of data points examined as compared to PBR and RCT1. Less data and the short range accentuates the chance variation where the other parameters could smooth out their chance variations with more data points and a wider range. Despite this accentuation of the chance variation, NCT r-factors still exceed the r-test threshold confirming linearity. The confirmed linear relationship between the base self-sufficiency parameters and the performance measures facilitate the sensitivity analysis presented in the next section.

Sensitivity

Sensitivity of base self-sufficiency is analyzed by looking at the effects which changes in PBR and RCT have on the individual performance measures. This analysis attempts not to equate the sensitivity of PBR to RCT since each of these indicators measure different aspects of base self-sufficiency. PBR measures the effectiveness of base self-sufficiency or the degree to which a base supports itself. RCT measures time efficiency, how fast a base processes a reparable asset through its repair cycle. The sensitivity of increasing PBR and RCT1 (up to one day), runs 20 through 27, is analyzed because of the

feasibility that increases in PBR, more base repairs, cause average repair times to increase. These sensitivity runs assume PBR increases above 10 percent require additional support equipment and/or manpower to raise PBR any further, thus offsetting any additional increases in RCT1.

To maintain consistency with the experimental design, PBR changes of one percent and RCT changes of a tenth of a day are the incremental basis for the sensitivity analysis. Because the results are basically linear, sensitivity is derived as an average for the full range of each parameter tested. For example, the sensitivity of PBR using the performance measure expected backorders is calculated by dividing 50 percent into the change in expected backorders for this range giving -.309379. Or for every one percent increase in PBR, expected backorders decrease by .309379. Table V presents the aggregate results. A negative sign indicates an inverse relationship.

TABLE V

Sensitivity Results

Improvement in	Causing a Corresponding Change to: E(b)	Fill Rt	Cost
PBR (all)	-.3093379	.0130196	-$409,002
PBR (partial)	-.4416537	.0185893	-$421,707
PBR/RCT (all)	-.2327552	.0097968	-$383,458
PBR/RCT (partial)	-.3305487	.0139130	-$388,106
RCT1	.2589643	-.1089967	$18,188
NCT	.0188667	-.0205600	$41,909

On the aggregate, expected backorders decrease as parameters improvements are made while the fill rate measure increases reacting in an inverse manner. A decline in the expected number of backorders improves the chances for on-the-shelf issues. Stockage cost, as base self-sufficiency improves, goes down because pipeline times decrease. Or to say it another way, as pipeline times decline, demand level loses reduce stockage costs. The remaining portion of this section is devoted to parameter sensitivity looking at PBR (runs 1 thru 8), RCT (runs 9 thru 19) which include RCT1 and NCT, and the combination of changing PBR and RCT1 upward (runs 20 thru 27). Favorable directions in the performance measures are characterized as a decline in expected backorders and stockage cost, and an increase in fill rate.

PBR. Expected backorders and stockage cost decline, and the fill rate increases as improvements are made in PBR. For each one percent increase in PBR, expected backorders decrease by .309 and stockage cost by $409,002. Fill rate increases by .013 for each percentage increase. If these performance measures are viewed without the EOQ deviation, further improvement is seen. For each one percent increase in PBR, expected backorders decrease by .442 and stockage cost by $421,707, and fill rate increases by .019; an improvement of .133, $12,705 and .006, respectively, over the range that includes the EOQ deviation. These results show the performance measures react favorably to improvements in PBR. As PBR increases, pipeline times fall. The smaller pipeline times in turn decrease the demand levels. The lower demand levels result in a lower stockage cost, but are not reduced to the point where performance levels begin to deteriorate. In fact the opposite is true, the demand levels are not lowered as much or not to an equivalent level as the

pipeline time reductions resulting in an overall improvement in expected backorders and the fill rate.

RCT. The sensitivity of RCT1 and NCT vary differently. On the whole, NCT is insensitive for all three of the performance measures. For every tenth of a day decrease in NCT, expected backorders decrease by .049 and stockage cost by $41,909, and the fill rate increases by .021. Although the performance measure trends are favorable, the changes are so small the output results remain nearly constant throughout the NCT sensitivity changes.

RCT1 is more sensitive for expected backorders and fill rate, but less sensitive than NCT for stockage cost. Again, all three performance measures reflect favorable trends. As RCT1 decreases by a tenth of a day, expected backorders decline by .259, fill rate increases by .109, and stockage cost decline by $18,188. All three of these trends are attributed to the RCT1 floor, otherwise the performance measures would react about the same for RCT1 as they did with NCT. For expected backorders and fill rate, RCT1 is significantly more sensitive than NCT. As for stockage cost, RCT1 is less sensitive than NCT. This is as expected since the four day RCT1 floor keeps demand levels artificially high as RCT1 decreases. These artificially high demand levels are also the reason for the favorable trends in the other two performance measures by adding more cushion to cover the pipeline times and uncertainty. Overall, RCT1 is more than five times more sensitive than NCT for the expected backorder and fill rate measures. For stockage cost, NCT is $23,721 more sensitive than RCT1 per a tenth of a day change. Next, the effects of increasing PBR and RCT1 together are examined.

PBR/RCT1. These sensitivity runs compare relative graphic and numeric results in terms of PBR. The sensitivity runs are designed to see the effects of improving PBR, thus increasing the number of repairs on base which in turn causes an increase in the average base repair time. The PBR/RCT1 sensitivity results are consistent with runs one through nine when just PBR varys. With all three performance measures, PBR/RCT1 results parallel those of the PBR runs. The results are not as favorable as the PBR runs because RCT1 counteracts, to a small degree, the sensitivity of PBR alone. On the average, expected backorders and stockage cost in these runs decline less than the PBR runs by .077 and $25,544, respectively. The fill rate increases less than the PBR runs by .004. The EOQ deviation has the same effect with these runs as with those that vary PBR alone. These results are as expected since the increases in RCT1 offset a portion of the favorable results occurring from the PBR increases.

Summary

The effects of base self-sufficiency, as measured by PBR and RCT, upon the performance measures of expected backorders, fill rate and stockage cost are linear with a 95 percent degree of confidence. However, when PBR increases by approximately 38 percent, expected backorders and fill rate take a marked adverse direction. This adverse direction, or EOQ deviation as it is referred to in this study, is due to the loss of the EOQ for those "XF" items with an initial PBR of zero. Stockage cost is relatively unaffected by the EOQ deviation because of the low unit cost for these items. Because the results are linear, sensitivity is measured by the average change in each performance measure for a one percent increase in PBR or a tenth of a day decrease

in RCT.

On the whole, expected backorders and stockage cost decrease as the base self-sufficiency parameters improve. The fill rate measure increases as improvement changes are made in PBR, RCT1 and NCT. Sensitivity of base self-sufficiency is summarized by looking at the effects of increasing PBR, decreasing RCT, and increasing PBR with an accompaning increase in RCT1:

PBR: PBR is favorably sensitive to all three of the performance measures. The adjusted demand levels more than compensate for the reduction in the pipeline times improving expected backorders and the fill rate. Stockage savings are substantial as a result of the reduced demand levels.

RCT: NCT is insensitive to all three performance measures. For RCT1, the four day floor plays a key role in this parameter's sensitivity. RCT1 is favorably sensitive to expected backorders and fill rate. This is caused by the maintenance of artificially high demand levels. These high demand levels also cause stockage cost to remain constant through the incremental improvements of RCT1.

PBR/RCT1: The results with these parameter changes are consistent with and parallel to the sensitivity of just improving PBR. Expected backorders and stockage cost decline, and the fill rate increases, at slower rates when compared to the sensitivity of PBR.

On the whole, PBR and RCT1 are sensitive parameters, as long as RCT1 operates with the four day floor. NCT is fairly insensitive. Now that the results are in, the next chapter makes some conclusions and managerial implications based on the research questions. In addition, these results lead to a number of recommendations also outlined in the following chapter.

V. Conclusions and Recommendations

Summary of the Research

This study determines the effects of improving base self-sufficiency on selected performance indicators. Base self-sufficiency is measured by PBR and RCT for those assets coded as reparable. PBR measures a base's repair capability or the ability to replenish its own stocks in support of the mission. RCT measures the time efficiency of processing spares through the base's repair cycle whether the item is repaired or not. Base self-sufficiency improvements are seen as increases in PBR or decreases in RCT. The effects of these increases or decreases are gauged by changes in the expected backorder, fill rate and stockage cost performance measures. Thus, the two investigative questions coincide with the two components of base self-sufficienc and ask how much does increasing PBR and decreasing RCT effect the selected performance indicators.

The model itself is the main thrust behind this examination providing base level managers a tool to assist them in evaluating their base self-sufficiency. The model replicates the Repair Cycle Demand Level (RCDL) inventory model used in the Standard Base Supply System (SBSS). The RCDL model calculates sufficient base stocks to cover base and depot replenishment pipelines, and variability of demand to achieve an 84 percent service level assuming a normal distribution. Other conventions in the model include an EOQ component for selected "XF" items and a four day RCT1 floor. The output of the RCDL model results in a demand level or the level of authorized stock for each item at a base. The demand level, pipeline times and the daily demand rate are

the parameters used to calculate the expected backorder and fill rate performance measures. These two measures are based on Palm's theorem which states that if demand arrives according to a poisson process, then the number of units in resupply is also poisson for any arbitrary resupply distribution. The poisson process selected for this study is the simple or constant poisson distribution. This distribution is used widely in describing demand and resupply probabilities inherent in most performance measures for solving inventory problems. The third performance measure, stockage cost, is simply the summation of the demand level for each item multiplied by its unit cost.

The methodology establishes the basis by which the research is conducted. The experimental design outlines the incremental changes made in the parameters and the ranges tested. PBR increases in total by 50 percent while the RCT range is restricted by a one day floor. RCT1 decreases in total by three days and NCT by one and a half days. The parameter ranges test two situations. First is to test the effects of improving base self-sufficiency achieved by the base alone. Second is to test the effects when additional support equipment and manpower are transferred to a base increasing that base's self-sufficiency. In addition, the experimental design outlines a range of parameter adjustments where an increase in PBR may spur an increase in RCT1 due to the additional number of repairs performed on base without any additional resources to accomplish these repairs.

The methodology also outlines the data base and the language used to build the model. The data is provided by the Air Force Logistics Management Center collected from the selected test base, RAF Upper Heyford, England. RAF Upper Heyford provides a large and varying

reparable asset data base frequently used in reparable item studies. The model uses the Fortran 77 language, as opposed to a simulation language, because of Fortran 77's analytical capability in performing quantitative problems and its large informational processing ability. In addition, Fortran 77 easily adapts to microcomputer use in the field or at base level.

The developed model accurately replicates the SBSS as shown by tests comparing the model's computations against manual calculations and actual SBSS results. The model also computes the performance measures accurately since there is very little difference between the model's results and computations derived from a set of standard poisson tables. Overall, the validation and verification tests prove the model provides the means of attaining sensitivity results to answer the investigative questions.

The results of this study found a linear relationship between PBR and RCT to the performance measures with a 95 percent degree of confidence. Because of this linearity, sensitivity is measured by the average change in each performance measure for a one percent increase in PBR or a tenth of a day decrease in RCT. As the base self-sufficiency parameters improve, expected backorders and stockage cost decline while the fill rate measure increases. PBR is a sensitive parameter for all three of the performance measures. RCT1 is also a sensitive parameter with the performance measures taking a favorable direction because of the four day floor. NCT is insensitive to all the performance measures. Increasing PBR and RCT1 together parallel the PBR runs, but are not quite as favorable. With these results, some additional remarks are made concerning the investigative questions.

Investigative Questions

The two investigative questions seek to measure the sensitivity of the parameters or provide an answer as to how much an increase in PBR and a decrease in RCT improve base performance indicators. These questions were answered in the last chapter in a purely numerical fashion without relating their effect to the Air Force supply system. The remaining portion of this chapter devotes itself toward relating the results to that system. To do this, a realistic range of PBR and RCT is established differentiating between what base managers can do without outside help and that when additional equipment and manpower is in place. As previously alluded to, PBR can reasonably increase by ten percent and RCT decrease by one day as a result of base managers selecting and implementing, without outside help, the stockage policies and methods to improve base self-sufficiency. The two investigative questions are discussed separately with this differentiation made.

Investigative Question 1. How much does an increase in PBR improve base performance indicators? If PBR increases by ten percent through better base stockage policies, RAF Upper Heyford could reduce the average number of backorders by 4.5. This is a 6.7 percent improvement. The fill rate improves by about two tenths of a percent. The most significant finding is a stockage savings of over five million dollars. This is a 10 percent decrease in the stockage requirements for only this one particular base. The results are just as dramatic as PBR increases further to 38 percent, the point just prior to the EOQ deviation. The EOQ deviation itself dampens improvements in the performance measures. If RAF Upper Heyford's PBR rises to 88 percent, significantly improving its repair capability through equipment and manpower additions, the

average number of backorders decrease by 15.5, or a 23 percent improvement, and the fill rate increases by more than a half percent. Stockage cost declines by an overwhelming 20.45 million dollars nearly reducing stockage requirements in half.

As one might reasonably expect, PBR could increase the average repair time because of the larger number of base repairs. If PBR increases by 10 percent and RCT1 by one day, the effects on expected backorders and fill rate are considerably less favorable than the effects of just increasing PBR. The improvement in expected backorders and the fill rate are cut in half when compared to the PBR runs. But, the stockage cost measure still declines at a healthy rate with a savings of over 4.2 million dollars. Extending these findings to a PBR increase of 50 percent and keeping the average repair time constant at the one day increase (since RCT1 would probably only increase initially due to the increase in the number of repairs without additional outside help), the performance measures are more consistent with the sensitivity of PBR alone. This of course requires the installation of additional repair equipment and the associated manpower requirements needed to support this higher level of base self-sufficiency.

Investigative Question 2. How much does a decrease in RCT improve base performance indicators? RCT sensitivity is dominated by the four day RCT1 floor. Excluding this floor, RCT1 changes have a similar effect on the performance measures as does NCT. NCT is insensitive showing only slight improvements in expected backorders and the fill rate. Stockage savings amounted to $628,000 for the entire NCT range tested, again portraying NCT's insensitivity. If RCT1 or the average repair time is reduced by one day through the efforts of base managers,

the average number of backorders decline by 2.7 or a four percent improvement with a fill rate increase of just over one tenth of a percent. Stockage cost only amounts to a $178,000 savings. Reducing RCT1 further (up to three days), with the help of additional equipment and manpower, reduces expected backorders at the same rate of decline. The average number of backorders are reduced by 7.8, an 11.6 percent improvement. The fill rate measure also changes at a constant rate with an improvement of over three tenths of a percent for the full three day range.

Putting the findings in realistic terms presents many conclusions and managerial implications. Those conclusions and implications are expanded further leading to a number of recommendations.

Conclusions, Managerial Implications and Recommendations

The most significant managerial implication of this research is the development of a management tool which base managers can use to evaluate their base self-sufficiency. This tool or the model developed for this research effort must now be replicated and sent to those base supply and maintenance managers in the field. Special care must be taken to ensure the replicated model is compatible with those systems available to base level managers and the data base is in the proper format and transferable to those systems. Although the results of this study specifically apply to RAF Upper Heyford, the aggregate trends are applicable to all Air Force bases having a repair capability. In other words, the numerical results will vary from base to base, but the sensitivity of the parameters are reflected Air Force wide.

There are many conclusions and recommendations derived from the aggregate trends. Improvements in PBR prove most beneficial whether

looking at those changes requiring outside help or those which base managers can produce only through their stockage policies and methods. A concerted effort should be made by each individual base to improve its PBR in order to receive the benefits of fewer backorders and an increased fill rate, and more importantly, to reduce stockage cost. Perhaps a centralized program within the Air Force to push bases for PBR improvements should be established. Although this is not a new idea, this study shows such an effort has merits. In addition, the stockage savings obtained from such improvements in base self-sufficiency could be funneled back into the base in the form of added stock to further increase the fill rate and decrease expected backorders. However, this study also indicates it is important that base level managers attempt to increase PBR without spurring an increase in the average repair time to prevent negations in the performance measures. One area of particular interest is those "XF" items having a low base repair rate. All too often these assets are treated strictly as "throw away" items. If more concern by base managers are made toward attempting to repair these items or acquire the capability to repair these items, significant savings could be made in stockage and replacement costs.

Serious consideration should be made toward stationing additional equipment and manpower, increasing PBR above that achieved through normal base self-help, to increase a base's repair capability. Of course a good portion of the cost for the additional equipment and manpower must be offset by stockage savings and savings derived from less transportation (assets going to and from the depots) and storage requirements. This study shows improvement in PBR as the result of additional repair resources, even though repair times may initially

increase, result in significant dollar savings, and improvement in the average number of backorders and fill rate.

As for RCT, improvements in only RCT1 are beneficial. These benefits are in the form of improvements in expected backorders and the fill rate. Stockage cost declines are neglible. NCT does show a little more stockage savings than RCT1, but not to any significant degree. Improvement changes in NCT have little effect on expected backorders and the fill rate. This points out the possible need to establish a NCT floor as exists for RCT1. If a four day floor gives improved performance for priority base maintenance turnaround actions, then why not do the same by evacuating carcasses to the depots quicker. It is noted, however, that NCT does not have as much impact as RCT1 because NCT is a smaller value. NCT is added to the order and ship time diluting its importance in the RCDL pipeline model. If a NCT floor is established, the exact level to set the floor should be determined in a manner commensurate with the average NRTS/condemned times prevalent throughout the Air Force. This study provides a NCT level of one base only which is not representive of the Air Force as a whole. The four day RCT1 floor provides improved performance for RAF Upper Heyford, and a possible two to three day floor might do the same for NCT.

There is one final managerial implication. This implication concerns the internal workings of the model and how parameter allocations are made to each item. The model applies the changes in the parameters equally to all items until the 99 percent ceiling for PBR or the one day floor for RCT is reached. In the real world, the change in a base's average PBR or RCT is not derived in such a manner. Some items would change drastically, some not at all, and others might fluctuate a

small degree in either a favorable or unfavorable direction. Table VI portrays an example of this implication by making a PBR increase of 10 percent.

TABLE VI

Parameter Adjustment Example

Item	Beginning Value	Model	Model Changes	Possible Real World	Real World Changes
1	.50	.625	+.125	.90	+.4
2	.40	.525	+.125	.35	-.05
3	.75	.875	+.125	.85	+.1
4	.00	.125	+.125	.05	+.05
5	.99	.99	0	.99	0
Base	.528	.628		.628	

The effect of the model's parameter allocations are not readily apparent or have little impact on the results except when viewing the EOQ deviation. The EOQ deviation might induce reluctance upon managers to raise PBR too much in order to avoid the detrimental effects of the EOQ deviation itself. In real life, the possibility of increasing the PBR of those "XF" items having a zero PBR to 50 percent or greater is small as compared to other items. Items authorized only field level repair, especially low cost items, are characterized by having little reparability and are frequently consumed in use. Therefore, raising a base's average PBR probably results more from increasing the PBR on "XD" items (authorized depot repair) by decreasing inadvertent transfers to depot or by transferring depot repair capability to the base. The overall result is the model accentuates the EOQ deviation more than is evident in the real world. This accentuating effect does not negate the

results, but merely indicates the EOQ deviation is less apparent in the real world than in the model. The results in this study would be more favorable if it were possible to more closely model realistic PBR increases which might occur at RAF Upper Heyford or any other base. This brings out the possibility for modifying the model to select only portions of the data base on such criteria as unit cost, ERRC, and daily demand rates. With such an option, base managers could evaluate changes in the parameters more realistically aligned to the feasibility of such changes and determine those categories of items providing the best performance. Such an option allows for further investigative research into base self-sufficiency.

Suggestions for Further Research

This research is centered between two other factors concerned with base self-sufficiency. At one extreme, base self-sufficiency is determined by the stockage policies and methods used by its managers. An investigation into those policies and methods giving the most effective improvement in PBR and RCT would benefit base managers. The model developed could aid this suggested investigation by measuring the effect those policies and methods have on the base self-sufficiency parameters.

At the other extreme, further investigation is required to expand the model developed to include performance indicators measuring aircraft availability. This expanded approach broadens the application of the model by allowing base managers to see the operational effects of base self-sufficiency. This suggested investigation requires lateral support, cannibalization, flying activity and other considerations be programmed in the model. In addition, such options as discussed before

as selecting different categories of items i.e., unit cost, ERRC and DDR, could also determine where the most benefits are derived.

As mentioned in the prior section, an investigation should be conducted analyzing the effects of establishing a NCT floor. Establishing such a RCDL restriction improves the expected backorder and the fill rate performance measures at the expense of decreasing some portion of the stockage savings. However, since NCT sensitivity to stockage cost is already negligible, further research in this area should show some encouraging results. The model developed in this study is adaptable for this research since the subroutine required is already incorporated in the model.

With research in the above areas, base managers would have a complete picture of the base self-sufficiency arena. This arena begins with the implementation of selected stockage policies and methods giving the best base self-sufficiency performance. It ends by providing base managers a complete tool for evaluating base self-sufficieny seeing the overall operational effects, as well as the direct stockage/supply measurement effects, and showing those managers what categories of items are most suited to improving base self-sufficiency.

Final Comments

Throughout this study, every effort is made not to compare PBR and RCT because of the lack of a common measurement base applicable to both parameters. In other words, given a level of base effort, how much does PBR increase or how much does RCT decrease? The exact answer to this is unknown, but a general feeling is offered based on prior base level experience. With the results of this study and for any given level of effort, primary emphasis should be placed on increasing PBR even if RCT

should increase by a small amount. This assertion is made because of the large amount of dollar savings derived by such an effort. Without even considering the transfer of additional equipment and manpower, the stockage savings alone are substantial if improvements are made Air Force wide. And, PBR increases also result in an increase in the fill rate, and a decline in expected backorders, storage facilities and transportation requirements. In these times of budgetary constraint, the need to accomplish the mission in the most cost and performance efficient manner becomes of paramount importance.

The model developed in this study will help base managers evaluate their base self-sufficiency. The model provides the necessary information for base managers to decide which base self-sufficiency avenues to pursue and the goals to establish. The only other ingredient required is the leadership and innovation needed to follow those avenues and meet those goals.

Appendix: Repair Cycle Base Self-Sufficiency Model

```
C     VARIABLES:
C
C     ACMNCT:  ACCUMULATES NCT TIME BELOW ONE DAY
C     ACMPBR:  ACCUMULATES PBR OVER 99 PERCENT
C     ACMRCT:  ACCUMULATES RCT TIME BELOW ONE DAY
C     ADJNCT:  ADJUSTS NCT AFTER CHANGE APPLIED
C     ADJPBR:  ADJUSTS PBR AFTER CHANGE APPLIED
C     ADJRCT:  ADJUSTS RCT AFTER CHANGE APPLIED
C     ALTNCT:  INPUTS NCT CHANGE
C     ALTPBR:  INPUTS PBR CHANGE
C     ALTRCT:  INPUTS RCT CHANGE
C     BASNCT:  BASE NCT
C     BASPBR:  BASE PBR
C     BASRCT:  BASE RCT
C     CONDA:  NUMBER OF ITEMS CONDEMNED IN CURRENT QUARTER
C     CONDB:  NUMBER OF ITEMS CONDEMNED IN FIRST PAST QUARTER
C     CONDC:  NUMBER OF ITEMS CONDEMNED IN SECOND PAST QUARTER
C     CONDD:  NUMBER OF ITEMS CONDEMNED IN THIRD PAST QUARTER
C     CONDE:  NUMBER OF ITEMS CONDEMNED IN FOURTH PAST QUARTER
C     CONST:  CONSTANT USED FOR INSURING CORRECT RECORD IS READ
C     CRD:  CUMULATIVE RECURRING DEMANDS
C     DL:  DEMAND LEVEL
C     DOFD:  DATE OF FIRST DEMAND
C     EBO:  EXPECTED BACKORDERS FOR EACH ITEM
C     ERD:  EXCEPTION REPAIR DAYS
C     EXCNCT:  EXCESS NCT TIME PER ITEM BELOW ONE DAY
C     EXCPBR:  EXCESS PBR PERCENT PER ITEM ABOVE 99 PERCENT
C     EXCRCT:  EXCESS RCT TIME PER ITEM BELOW ONE DAY
C     FR:  ITEM FILL RATE
C     I:  COUNTER FOR DO LOOPS
C     INCNCT:  INCREMENTAL AMOUNT OF TIME TO ADJUST NCT
C     INCPBR:  INCREMENTAL PERCENTAGE TO ADJUST PBR
C     INCRCT:  INCREMENTAL AMOUNT OF TIME TO ADJUST RCT
C     IND:  INDICATOR FOR ENTERING FILL RATE SUBROUTINE
C     M:  NUMBER OF RECORDS REQUIRING PBR ADJUSTMENT
C     P:  NUMBER OF RECORDS REQUIRING RCT ADJUSTMENT
C     Q:  NUMBER OF RECORDS REQUIRING NCT ADJUSTMENT
C     N:  NUMBER OF TOTAL RECORDS
C     NEWEBO:  NEW EXPECTED  BACKORDER FIGURE FOR THE BASE
C     NEWFR:  NEW FILL RATE FOR THE BASE
C     NWCOST:  NEW STOCKAGE COST
C     NNRTS:  NUMBER OF NRTS ITEMS
C     NREP:  NUMBER OF REPAIRED ITEMS
C     NRTSA:  NUMBER OF ITEMS NRTS IN CURRENT QUARTER
C     NRTSB:  NUMBER OF ITEMS NRTS IN FIRST PAST QUARTER
C     NRTSC:  NUMBER OF ITEMS NRTS IN SECOND PAST QUARTER
C     NRTSF:  NUMBER OF ITEMS NRTS IN THIRD PAST QUARTER
C     NRTSE:  NUMBER OF ITEMS NRTS IN FOURTH PAST QUARTER
C     NRTSDA:  NRTS/CONDEMNED DAYS CURRENT QUARTER
C     NRTSDB:  NRTS/CONDEMNED DAYS FIRST PAST QUARTER
C     NRTSDC:  NRTS/CONDEMNED DAYS SECOND PAST QUARTER
C     NRTSDD:  NRTS/CONDEMNED DAYS THIRD PAST QUARTER
C     NRTSD:  NRTS DAYS
C     PERCHG:  PERCENT CHANGE IN EXPECTED BACKORDERS
```

```
C      REPD:  REPAIR DAYS
C      REPDA:  REPAIR DAYS CURRENT QUARTER
C      REPDB:  REPAIR DAYS FIRST PAST QUARTER
C      REPDC:  REPAIR DAYS SECOND PAST QUARTER
C      REPDD:  REPAIR DAYS THIRD PAST QUARTER
C      REPDE:  REPAIR DAYS FOURTH PAST QUARTER
C      RI:  ROUTING IDENTIFIER
C      RTSA:  NUMBER OF REPAIRED ITEMS CURRENT QUARTER
C      RTSB:  NUMBER OF REPAIRED ITEMS FIRST PAST QUARTER
C      RTSC:  NUMBER OF REPAIRED ITEMS SECOND PAST QUARTER
C      RTSD:  NUMBER OF REPAIRED ITEMS THIRD PAST QUARTER
C      RTSE:  NUMBER OF REPAIRED ITEMS FOURTH PAST QUARTER
C      SBCOST:  DOLLAR AMOUNT STOCKED PER LINE ITEM
C      SET:  DIFFERENTIATES WHETHER AN ITEM HAS INITIALLY PROCESSED
C            THRU ADJUSTMENT SUBROUTINES
C      SUMDL:  TOTAL DEMAND LEVEL FOR THE BASE
C      SUMFR:  FILL RATE FOR ALL ITEMS TOGETHER
C      SUMEBO:  EXPECTED BACKORDERS FOR THE BASE
C      TNNRTS:  TOTAL NUMBER OF NRTS ITEMS FOR THE BASE
C      TNREP:  TOTAL NUMBER OF REPAIRED ITEMS FOR THE BASE
C      TNRTSD:  NRTS DAYS FOR THE BASE
C      TNREPD:  REPAIR DAYS FOR THE BASE
C      TOTREQ:  TOTAL NUMBER OF REQUESTS
C      X:  LOGICAL COMPARE FOR LOOPING BACK
C
C
C      ARRAYS:
C
C      COST:  UNIT COST
C      DDR:  DAILY DEMAND RATE
C      ERRC:  EXPENDABILITY RECOVERABILITY REPARABILITY COST CODE
C      NEWNCT:  NEW ADJUSTED NCT
C      NEWPBR:  NEW ADJUSTED PBR
C      NEWRCT:  NEW ADJUSTED RCT
C      NCT:  AVERAGE NRTS/CONDEMNED TIME
C      PBR:  PERCENT BASE REPAIR
C      RCT:  AVERAGE REPAIR TIME
C      OST:  ORDER AND SHIP TIME
C
C
C      REPAIR CYCLE BASE SELF-SUFFICIENCY MODEL:
C
       CHARACTER ERRC(4000)*,RI*3
       INTEGER RTSA,RTSB,RTSC,RTSD,RTSE,CONDA,CONDB,CONDC,CONDD,CONDE
       INTEGER REPDE,IND
       INTEGER NRTSA,NRTSB,NRTSC,NRTSF,NRTSE,REPDA,REPDB,REPDC,REPDD
       INTEGER NRTSDA,NRTSDB,NRTSDC,NRTSDD
       INTEGER I,M,N,P,Q,ERD,SET,Z,SUMDL,CONST,DOFD,DL,CRD
       INTEGER OST(4000),NREP,NNRTS,REPD,NRTSD
       INTEGER TNREP,TNNRTS,TREPD,TNRTSD
       REAL COST(4000),DDR(4000),PBR(4000),RCT(4000),NCT(4000)
       REAL EBO,BASPBR,BASRCT,BASNCT,SUMEBO,NEWEBO
       REAL NEWPBR(4000),NEWRCT(4000),NEWNCT(4000)
       REAL INCPBR,INCRCT,INCNCT,ADJPBR,ADJRCT,ADJNCT
```

```
      REAL EXCPBR,EXCRCT,EXCNCT,ACMPBR,ACMRCT,ACMNCT
      REAL PERCHG,ALTPBR,ALTRCT,ALTNCT,TOCOST
      REAL SUMFR,FR,SUMDDR,NWCOST,NEWFR,TOTREQ
      LOGICAL X
      DATA N,M,P,Q/4*0/
      DATA ACMPBR,ACMRCT,ACMNCT,SUMEBO,NEWEBO,TOCOST/6*0./
      DATA TNREP,TNNRTS,TREPD,TNRTSD,SUMDL/5*0/
      DATA SUMFR,SUMDDR,NWCOST,NEWFR/4*0./
C
C     READS INPUT RECORDS AND CALCULATES DEMAND LEVELS, TOTAL COST
C     AND EXPECTED BACKORDERS:
C
      DO 100 I=1,4000
   50 READ(2,110,END=120)CONST,ERRC(I),COST(I),ERD,CRD,DOFD,RI,
     *RTSA,RTSB,RTSC,RTSD,RTSE,CONDA,CONDB,CONDC,CONDD,CONDE,
      IF(CONST.NE.1)THEN
      PRINT*,'RECORDS OUT OF SEQUENCE: ',I
      GO TO 9999
      ENDIF
      READ(2,115,END=120)CONST,NRTSA,NRTSB,NRTSC,NRTSF,NRTSE,REPDA,
     *REPDB,REPDC,REPDD,REPDE,NRTSDA,NRTSDB,NRTSDC,NRTSDC
      IF(CONST.NE.2)THEN
      PRINT*,'RECORDS OUT OF SEQUENCE: ',I
      GO TO 9999
      ENDIF
      IF(CRD.EQ.0)GO TO 50
      IF(ERD.GT.0)GO TO 50
      NREP=RTSA+RTSB+RTSC+RTSD+RTSE
      NNRTS=CONDA+CONDB+CONDC+CONDD+CONDE+NRTSA+NRTSB+NRTSC+NRTSF+NRTSE
      REPD=REPDA+REPDB+REPDC+REPDD+REPDE
      NRTSD=NRTSDA+NRTSDB+NRTSDC+NRTSDD
      CALL CALDDR(CRD,DOFD,I,DDR)
      CALL CALOST(RI,OST,I)
      IF((NREP+NNRTS).EQ.0)THEN
      PBR(I)=0.
      GO TO 55
      ENDIF
      PBR(I)=(NREP*1.)/(NREP+NNRTS*1.)
      Z=NREP+NNRTS
      IF(NREP.EQ.Z)THEN
      PBR(I)=.99
      ENDIF
   55 IF(NREP.EQ.0)THEN
      RCT(I)=4
      GO TO 60
      ENDIF
      RCT(I)=(REPD*1.)/(NREP*1.)
      IF(NREP.LT.4.AND.ERRC(I).EQ.'XD1'.AND.RCT(I).GT.6)RCT(I)=6
      IF(NREP.LT.4.AND.ERRC(I).NE.'XD1'.AND.RCT(I).GT.9)RCT(I)=9
   60 IF(NNRTS.EQ.0)THEN
      NCT(I)=4
      GO TO 70
      ENDIF
      NCT(I)=(NRTSD*1.)/(NNRTS*1.)
```

```
      IF(NNRTS.LT.4.AND.NCT(I).GT.6)NCT(I)=6
   70 N=N+1
      TNREP=TNREP+NREP
      TNNRTS=TNNRTS+NNRTS
      TREPD=TREPD+REPD
      TNRTSD=TNRTSD+NRTSD
      IND=0
      CALL DEMLEV(ERRC,COST,DDR,OST,PBR,RCT,NCT,EBO,I,SBCOST,DL,FR,IND)
      SUMEBO=SUMEBO+EBO
      SUMFR=SUMFR+FR
      TOTREQ=SUMFR
      SUMDDR=SUMDDR+DDR(I)
      SUMDL=SUMDL+DL
      TOCOST=TOCOST+SBCOST
  100 CONTINUE
  110 FORMAT(15X,I1,A3,F8.2,I2,I6,I4,A3,10I3)
  115 FORMAT(15X,I1,5I3,5I4,4I3)
C
C     CALCULATES ACTUAL BASE PBR, RCT AND NCT, AND ACCEPTS
C     PARAMETER CHANGES:
C
  120 BASPBR=(TNREP*1.)/((TNREP+TNNRTS)*1.)
      BASRCT=(TREPD*1.)/(TNREP*1.)
      BASNCT=(TNRTSD*1.)/(TNNRTS*1.)
      PRINT*,'TOTAL LINE ITEMS: ',N
      PRINT*,'TOTAL DEMAND LEVEL: ',SUMDL
      PRINT*,'TOTAL COST: ',TOCOST
      SUMFR=((SUMFR-SUMEBO)/SUMFR)*100
      IND=1
  130 PRINT*,'BASE PBR: ',BASPBR
      PRINT*,'BASE RCT: ',BASRCT
      PRINT*,'BASE NCT: ',BASNCT
      SET=0
      SUMDL=0
      PRINT*,'EXPECTED BACKORDERS: ',SUMEBO
      PRINT*,'FILL RATE: ',SUMFR
      PRINT*,' '
      PRINT*,'ENTER PARAMETER CHANGES, IF NO CHANGE,'
      PRINT*,'ENTER A ZERO '
      PRINT*,'NEW PBR?'
      READ*,ALTPBR
      PRINT*,'NEW RCT?'
      READ*,ALTRCT
      PRINT*,'NEW NCT?'
      READ*,ALTNCT
      IF(ALTPBR.EQ.0.)ALTPBR=BASPBR
      IF(ALTRCT.EQ.0.)ALTRCT=BASRCT
      IF(ALTNCT.EQ.0.)ALTNCT=BASNCT
      INCPBR=ALTPBR-BASPBR
      INCRCT=BASRCT-ALTRCT
      INCNCT=BASNCT-ALTNCT
```

```
C     APPLIES INPUT PARAMETER CHANGES TO RECORDS:
C
      DO 300 I=1,N
      IF(INCPBR.NE.O.)THEN
      CALL CHGPBR(PBR,INCPBR,ADJPBR,EXCPBR,M,I,SET)
      ACMPBR=ACMPBR+EXCPBR
      EXCPBR=O.
      NEWPBR(I)=ADJPBR
      ELSE
      NEWPBR(I)=PBR(I)
      ENDIF
      IF(INCRCT.NE.O.)THEN
      CALL CHGRCT(RCT,INCRCT,ADJRCT,EXCRCT,P,I,SET)
      ACMRCT=ACMRCT+EXCRCT
      EXCRCT=O.
      NEWRCT(I)=ADJRCT
      ELSE
      NEWRCT(I)=RCT(I)
      ENDIF
      IF(INCNCT.NE.O.)THEN
      CALL CHGNCT(NCT,INCNCT,ADJNCT,EXCNCT,Q,I,SET)
      ACMNCT=ACMNCT+EXCNCT
      EXCNCT=O.
      NEWNCT(I)=ADJNCT
      ELSE
      NEWNCT(I)=NCT(I)
      ENDIF
  300 CONTINUE
  400 INCPBR=O.
      INCRCT=O.
      INCNCT=O.
      IF(ACMPBR.NE.O.)INCPBR=ACMPBR/M
      IF(ACMRCT.NE.O.)INCRCT=ACMRCT/P
      IF(ACMNCT.NE.O.)INCNCT=ACMNCT/Q
      SET=1
      M=0
      P=0
      Q=0
      ACMPBR=O.
      ACMRCT=O.
      ACMNCT=O.
      IF(INCPBR.NE.O..OR.INCRCT.NE.O..OR.INCNCT.NE.O.)THEN
      CALL CHANGE(NEWPBR,NEWRCT,NEWNCT,INCPBR,INCRCT,INCNCT,
     *ACMPBR,ACMRCT,ACMNCT,M,P,Q,N,SET)
      ELSE
      GO TO 500
      ENDIF
      GO TO 400
```

```
C     CALCULATES NEW DEMAND LEVELS, TOTAL COST, EXPECTED BACKORDERS
C     AND FILL RATE:
C
  500 DO 600 I=1,N
      CALL DEMLEV(ERRC,COST,DDR,OST,NEWPBR,NEWRCT,NEWNCT,EBO,I,SBCOST,
     *DL,FR,IND)
      NEWEBO=NEWEBO+EBO
      SUMDL=SUMDL+DL
      NWCOST=NWCOST+SBCOST
  600 CONTINUE
      PERCHG=(1-(NEWEBO/SUMEBO)*100
      PRINT*,'PARAMETERS ARE: '
      PRINT*,'PBR: ',ALTPBR
      PRINT*,'RCT: ',ALTRCT
      PRINT*,'NCT: ',ALTNCT
      PRINT*,' '
      PRINT*,'TOTAL DEMAND LEVEL: ',SUMDL
      PRINT*,'TOTAL COST: ',NWCOST
      PRINT*,'SAVINGS: ',(TOCOST-NWCOST)
      PRINT*,'NEW EXPECTED BACKORDERS: ',NEWEBO
      PRINT*,'PERCENT CHANGE: ',PERCHG,'%'
      NEWFR=((TOTREQ-NEWEBO)/TOTREQ)*100
      PRINT*,'NEW FILL RATE: ',NEWFR
      PRINT*,'CHANGE IN FILL RATE: ',(NEWFR-SUMFR)
      NEWFR=0.
      NEWEBO=0.
      SUMDL=0
      NWCOST=0.
      PRINT*,' '
      PRINT*,'IF YOU WANT TO INPUT MORE PARAMETER'
      PRINT*,'CHANGES, ENTER A T'
      READ*,X
      IF(X)GO TO 130
 9999 END
C
C
C     CALCULATES DEMAND LEVELS:
C
      SUBROUTINE DEMLEV(ERRC,COST,DDR,OST,PBR,RCT,NCT,EBO,I,
     *SBCOST,DL,FR,IND)
      INTEGER DL,OST(I),I,IND
      REAL COST(I),DDR(I),PBR(I),RCT(I),NCT(I),EBO,EOQ
      REAL T,SLQ,C,SBCOST
      CHARACTER ERRC(I)*3
      CALL TCHG(PBR,RCT,NCT,OST,T,I)
      IF(ERRC(I).EQ.'XF3'.AND.PBR(I).LT..5.AND.COST(I).LT.750.)THEN
      EOQ=(6.3*SQRT(DDR(I)*365*COST(I)))/COST(I)
      ELSE
      EOQ=0.
      ENDIF
      IF(COST(I).GR.750.)THEN
      C=.5
      ELSE
```

```
      C=.9
      ENDIF
      DL=INT((DDR(I)*T)+SLQ+EOQ+C)
      SBCOST=DL*COST(I)
      T=(PBR(I)*RCT(I))+((1-PBR(I))*NCT(I)+OST(I)))
      CALL CALFR(DL,T,DDR,I,FR)
      ENDIF
      END
C
C
C     CALCULATES EXPECTED BACKORDERS:
C
      SUBROUTINE EXPEBO(DL,T,DDR,I)
      INTEGER DL,X,I,SUBFAC,J
      REAL T,DDR(I),EBO,K,SUBEBO
      DOUBLE PRECISION FAC,PBA,PBB,PB,PX
      EBO=0.
      X=0
      IF(DL.EQ.0)THEN
      EBO=DDR(I)*T
      GO TO 1170
      ENDIF
      X=DL
 1100 X=X+1
      FAC=0.
      IF(X.GE.2)THEN
      DO 1150 J=2,X
      K=REAL(J)
      FAC=FAC+LOG(K)
 1150 CONTINUE
      ENDIF
      PBA=X*LOG(DDR(I)*T)
      PBB=(-DDR(I)*T)
      PB=PBA+PBB
      PX=PB-FAC
      PX=EXP(PX)
      SUBEBO=(X-DL)*PX
      EBO=EBO+SUBEBO
      IF(PX.GE..0001)GO TO 1100
 1170 END
C
C
C     ADJUSTS PBR:
C
      SUBROUTINE CHGPBR(PBR,INCPBR,ADJPBR,EXCPBR,A,I,SET)
      REAL PBR(I),INCPBR,ADJPBR,EXCPBR
      INTEGER A,I,SET
      IF(PBR(I).EQ..99)THEN
      ADJPBR=.99
      IF(SET.EQ.1)THEN
      GO TO 2100
      ENDIF
      EXCPBR=INCPBR
      GO TO 2100
```

```
      ENDIF
      ADJPBR=PBR(I)+INCPBR
      IF(ADJPBR.GE..99)THEN
      EXCPBR=ADJPBR-.99
      ADJPBR=.99
      GO TO 2100
      ENDIF
      A=A+1
 2100 END
C
C
C     ADJUSTS RCT:
C
      SUBROUTINE CHGRCT(RCT,INCRCT,ADJRCT,EXCRCT,B,I,SET)
      REAL RCT(I),INCRCT,ADJRCT,EXCRCT
      INTEGER B,I,SET
      IF(INCRCT.LT.0.)GO TO 3000
      IF(RCT(I).EQ.1.)THEN
      ADJRCT=1.
      IF(SET.EQ.1.)GO TO 3100
      EXCRCT=INCRCT
      GO TO 3100
      ENDIF
 3000 ADJRCT=RCT(I)-INCRCT
      IF(INCRCT.LT.0.)GO TO 3100
      IF(ADJRCT.LE.1.)THEN
      EXCRCT=1.-ADJRCT
      ADJRCT=1.
      GO TO 3100
      ENDIF
      B=B+1
 3100 END
C
C
C     ADJUSTS NCT:
C
      SUBROUTINE CHGNCT(NCT,INCNCT,ADJNCT,EXCNCT,C,I,SET)
      REAL NCT(I),INCNCT,ADJNCT,EXCNCT
      IF(NCT(I).EQ.1.)THEN
      ADJNCT=1.
      IF(SET.EQ.1)GO TO 4100
      EXCNCT=INCNCT
      GO TO 4100
      ENDIF
      ADJNCT=NCT(I)-INCNCT
      IF(ADJNCT.LE.1.)THEN
      EXCNCT=1.-ADJNCT
      ADJNCT=1.
      GO TO 4100
      ENDIF
      C=C+1
 4100 END
```

```
C     CONTROLS THE ADJUSTMENT OF THE PARAMETERS AND
C     APPLICABLE SUBROUTINES:
C
      SUBROUTINE CHANGE(NEWPBR,NEWRCT,NEWNCT,INCPBR,INCRCT,INCNCT,
     *ACMPBR,ACMRCT,ACMNCT,M,P,Q,N,SET)
      REAL NEWPBR(N),NEWRCT(N),NEWNCT(N),INCPBR,INCRCT,INCNCT
      REAL ACMPBR,ACMRCT,ACMNCT
      INTEGER M,P,Q,N,I,SET
      DO 5100 I=1,N
      IF(INCPBR.NE.0.)THEN
      CALL CHGPBR(NEWPBR,INCPBR,ADJPBR,EXCPBR,M,I,SET)
      ACMPBR=ACMPBR+EXCPBR
      EXCPBR=0.
      NEWPBR(I)=ADJPBR
      ENDIF
      IF(INCRCT.NE.0.)THEN
      CALL CHGRCT(NEWRCT,INCRCT,ADJRCT,EXCRCT,P,I,SET)
      ACMRCT=ACMRCT+EXCRCT
      EXRCT=0.
      NEWRCT(I)=ADJRCT
      ENDIF
      IF(INCNCT.NE.0.)THEN
      CALL CHGNCT(NEWNCT,INCNCT,ADJNCT,EXCNCT,Q,I,SET)
      ACMNCT=ACMNCT+EXCNCT
      EXCNCT=0.
      NEWNCT(I)=ADJNCT
      ENDIF
 5100 CONTINUE
      END
C
C
C     CALCULATES T FOR USE IN COMPUTING DEMAND LEVELS:
C
      SUBROUTINE TCHG(PBR,RCT,NCT,OST,T,I)
      INTEGER I,OST(I)
      REAL PBR(I).RCT(I),NCT(I)
      REAL PBRA,RCTA,NCTA
      PBRA=PBR(I)
      IF(RCT(I).LT.4.)THEN
      RCTA=4.
      ELSE
      RCTA=RCT(I)
      ENDIF
      NCTA=NCT(I)
      T=(PBRA*RCTA)+((1-PBRA)*(NCTA+OST(I)))
      END
C
C
C     COMPUTES DAILY DEMAND RATE:
C
      SUBROUTINE CALDDR(CRD,DOFD,I,DDR)
      INTEGER DOFD,I,DAYS,CRD
      REAL DDR(I)
```

```
      IF(DOFD.GE.3000)THEN
      DAYS=3270-DOFD
      ELSE
      DAYS=(2365-DOFD)+270
      ENDIF
      IF(DAYS.LT.180)THEN
      DDR(I)=(CRD*1.)/(180*1.)
      ELSE
      DDR(I)=(CRD*1.)/(DAYS*1.)
      ENDIF
      END
C
C
C     ASSIGN OST ACCORDING TO THE ROUTING IDENTIFIER:
C
      SUBROUTINE CALOST(RI,OST,I)
      CHARACTER RI*3
      INTEGER OST(I),I
      IF(RI.EQ.'AKZ')THEN
      OST(I)=62
      ELSEIF(RI.EQ.'B14')THEN
      OST(I)=42
      ELSEIF(RI.EQ.'FFZ')THEN
      OST(I)=48
      ELSEIF(RI.EQ.'FHZ')THEN
      OST(I)=41
      ELSEIF(RI.EQ.'FLZ')THEN
      OST(I)=39
      ELSEIF(RI.EQ.'FPZ')THEN
      OST(I)=63
      ELSEIF(RI.EQ.'GAO')THEN
      OST(I)=61
      ELSEIF(RI.EQ.'GNO')THEN
      OST(I)=65
      ELSEIF(RI.EQ.'GSA')THEN
      OST(I)=58
      ELSEIF(RI.EQ.'S9C')THEN
      OST(I)=52
      ELSEIF(RI.EQ.'S9E')THEN
      OST(I)=41
      ELSEIF(RI.EQ.'S9G')THEN
      OST(I)=38
      ELSEIF(RI.EQ.'S9I')THEN
      OST(I)=56
      ELSEIF(RI.EQ.'S9T')THEN
      OST(I)=53
      ELSEIF(RI.EQ.'B16')THEN
      OST(I)=47
      ELSEIF(RI.EQ.'COS')THEN
      OST(I)=44
      ELSEIF(RI.EQ.'DCB')THEN
      OST(I)=40
      ELSEIF(RI.EQ.'DEH')THEN
      OST(I)=13
```

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      ELSEIF(RI.EQ.'FGZ')THEN
      OST(I)=44
      ELSEIF(RI.EQ.'FPD')THEN
      OST(I)=59
      ELSEIF(RI.EQ.'GFO')THEN
      OST(I)=75
      ELSEIF(RI.EQ.'GKO')THEN
      OST(I)=71
      ELSEIF(RI.EQ.'GWO')THEN
      OST(I)=75
      ELSEIF(RI.EQ.'HR1')THEN
      OST(I)=23
      ELSEIF(RI.EQ.'N32')THEN
      OST(I)=43
      ELSE
      OST(I)=48
      ENDIF
      END
C
C
C     CALCULATES FILL RATE:
C
      SUBROUTINE CALFR(DL,T,DDR,I,FR)
      INTEGER DL,I,X,J
      REAL DDR(I),FR,K,SUBFR
      DOUBLE PRECISION FAC,PBA,PBB,PB,PX
      FR=0.
      X=-1
 6100 X=X+1
      FAC=0.
      IF(X.GE.2)THEN
      DO 6150 J=2,X
      K=REAL(J)
      FAC=FAC+LOG(K)
 6150 CONTINUE
      ENDIF
      PBA=X*LOG(DDR(I)*T)
      PBB=(-DDR(I)*T)
      PB=PBA+PBB
      PX=PB-FAC
      PX=EXP(PX)
      SUBFR=PX*X
      FR=FR+SUBFR
      IF(PX.GE..0001)GO TO 6100
 6170 CONTINUE
      END
```

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The primary emphasis in this study is to develop a tool for use by base level managers in evaluating base self-sufficiency. Base self-sufficiency is gauged by the percent base repair (PBR) and repair cycle time (RCT) for those assets coded as reparable. This study focuses on incrementally increasing PBR and decreasing RCT to determine their effects on expected backorders, the fill rate and stockage cost.

The tool or model developed in this effort is a Fortran 77 program replicating existing Repair Cycle Demand Level (RCDL) conventions employed in the Air Force's Standard Base Supply System (SBSS). The Fortran 77 mode is used primarily because of its analytical capability and adaptability for microcomputer use at the base level. The data processed through the model is from RAF Upper Heyford, England collected by the Air Force Logistics Management Center.

In evaluating the sensitivity of PBR and RCT, the simple poisson distribution is used to describe demand and resupply probabilities. This particular distribution is widely used for solving inventory problems, it accurately describes reparable item demand, and is not computationally burdensome.

The results generally show RCT, for repaired items only (RCT1), and PBR are sensitive to the performance measures. RCT1 is sensitive because of an existing four day floor used in the RCDL model. RCT for unserviceable items sent to depot (NCT) is insensitive. Of particular significance is the sensitivity of PBR in reference to the stockage cost measure; raising PBR decreases stockage cost dramatically.

This study recommends the developed model be replicated and sent out to the field for base level use. In addition, a recommendation is made for Air Force managers to emphasize and push for increasing base repair capabilities to reap the benefits of the savings derived and improve operational stockage performance.